CALIFORNIA ENERGY COMMISSION

Commercial Building Energy Benchmarking

TECHNICAL REPORT

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CALIFORNIA ENERGY COMMISSION

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Preface

The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The Program's final report and its attachments are intended to provide a complete record of the objectives, methods, findings and accomplishments of the High Performance Commercial Building Systems (HPCBS) Program. This Commercial Building Energy Benchmarking attachment provides supplemental information to the final report (Commission publication # 500-03-097-A1). The reports, and particularly the attachments, are highly applicable to architects, designers, contractors, building owners and operators, manufacturers, researchers, and the energy efficiency community.

This document is the first of 22 technical attachments to the final report, and consists of research reports:

- Development of a California Commercial Building Energy Benchmarking Database [E2P2.1T1d]
- School Energy Use Benchmarking and Monitoring [E2P2.1T3d]
- Final benchmarking tool report [E2P2.1T1f]

The Buildings Program Area within the Public Interest Energy Research (PIER) Program produced this document as part of a multi-project programmatic contract (#400-99-012). The Buildings Program includes new and existing buildings in both the residential and the nonresidential sectors. The program seeks to decrease building energy use through research that will develop or improve energy-efficient technologies, strategies, tools, and building performance evaluation methods.

For the final report, other attachments or reports produced within this contract, or to obtain more information on the PIER Program, please visit http://www.energy.ca.gov/pier/buildings or contact the Commission's Publications Unit at 916-654-5200. The reports and attachments are also available at the HPCBS website: http://buildings.lbl.gov/hpcbs/.

Abstracts

Development of a California Commercial Building Energy Benchmarking Database

This web site contains the Cal-Arch interactive software, and can be accessed at: http://poet.lbl.gov/cal-arch/ The following reports expands on the information, and gives the background and information used in developing the software.

California Commercial Building Energy Benchmarking Final Project Report

The primary goal of Task 2.1.1 Web-based Benchmarking was the development of a web-based benchmarking tool, dubbed Cal-Arch, for benchmarking energy use in California commercial buildings. While there were several other benchmarking tools available to California consumers prior to the development of Cal-Arch, there were none that were based solely on California data. Most available benchmarking information, including the Energy Star performance rating, were developed using DOE's Commercial Building Energy Consumption Survey (CBECS), which does not provide state-level data. Each database and tool has advantages as well as limitations, such as the number of buildings and the coverage by type, climate regions and end uses.

There is considerable commercial interest in benchmarking because it provides an inexpensive method of screening buildings for tune-ups and retrofits. However, private companies who collect and manage consumption data are concerned that the identities of building owners might be revealed and hence are reluctant to share their data. The California Commercial End Use Survey (CEUS), the primary source of data for Cal-Arch, is a unique source of information on commercial buildings in California. It has not been made public; however, it was made available by CEC to LBNL for the purpose of developing a public benchmarking tool.

The remainder of this report is organized as follows:

Section 2. Approach. Discusses the technical and outreach activities undertaken in the web-based benchmarking project.

Section 3. Outcomes. Describes the project results, including the current implementation of Cal-Arch.

Section 4. Conclusions and Recommendations. Discusses what has been learned during this project and plans and recommendations for future action.

Additional information is included in the appendices.

School Energy Use Benchmarking and Monitoring

The second item is a report that determines how a small sample of people involved in operating buildings can make use of benchmarked energy-consumption data. The focus of this study is on building owners. Are they interested in benchmarks? How will they use them? Are they interested in sharing energy information with others in similar positions, as a means of comparing notes and determining further steps to control energy costs?

A second but still crucial element of Task 2.1.3 is the application of advanced technology to obtain energy information at selected sites. To compare energy consumption at a particular building to an EUI-based benchmark requires nothing more than a year of energy bills. The user of a benchmarking tool then must assess why the EUI for the site in question differs from that of supposedly comparable buildings. Longer hours of operation? Special equipment? More widgets produced? Not yet able to afford an overdue lighting retrofit? End-use information can be used to pinpoint areas of relatively high energy consumption. If a benchmark includes enduse information, then end-use information for the site in question is essential.

California Energy Commission
Public Interest Energy Research Program

HPCBS # E2P2.1T1f

HPCBS

High Performance Commercial Building Systems

California Commercial Building Energy Benchmarking
Final Project Report

Element 2. Life-Cycle Tools
Project 2.1 - Benchmarking and Performance Metrics
Task 2.1.1 - Final benchmarking tool and report evaluating benchmarking with advanced normalization procedures

Satkartar Kinney and Mary Ann Piette
Lawrence Berkeley National Laboratory
May 2003

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Table of Contents

1. Introduction

Building energy benchmarking is the comparison of whole-building energy use relative to a set of similar buildings. It provides a useful starting point for individual energy audits and for targeting buildings for energy-saving measures in multiple-site audits. Benchmarking is of interest and practical use to a number of groups. Energy service companies and performance contractors communicate energy savings potential with "typical" and "best-practice" benchmarks while control companies and utilities can provide direct tracking of energy use and combine data from multiple buildings. Benchmarking is also useful in the design stage of a new building or retrofit to determine if a design is relatively efficient. Energy managers and building owners have an ongoing interest in comparing energy performance to others. Large corporations, schools, and government agencies with numerous facilities also use benchmarking methods to compare their buildings to each other.

The primary goal of Task 2.1.1 Web-based Benchmarking was the development of a web-based benchmarking tool, dubbed Cal-Arch, for benchmarking energy use in California commercial buildings. While there were several other benchmarking tools available to California consumers prior to the development of Cal-Arch, there were none that were based solely on California data. Most available benchmarking information, including the Energy Star performance rating, were developed using DOE's Commercial Building Energy Consumption Survey (CBECS), which does not provide state-level data. Each database and tool has advantages as well as limitations, such as the number of buildings and the coverage by type, climate regions and end uses.

There is considerable commercial interest in benchmarking because it provides an inexpensive method of screening buildings for tune-ups and retrofits. However, private companies who collect and manage consumption data are concerned that the identities of building owners might be revealed and hence are reluctant to share their data. The California Commercial End Use Survey (CEUS), the primary source of data for Cal-Arch, is a unique source of information on commercial buildings in California. It has not been made public; however, it was made available by CEC to LBNL for the purpose of developing a public benchmarking tool.

The remainder of this report is organized as follows:

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Additional information is included in the appendices.

2. Approach

This section describes the technical and outreach activities in the web-based benchmarking project. First and foremost is the development of Cal-Arch. Additional technical activities include the development of a specification for Cal-Arch, the evaluation of related benchmarking methodologies, and analysis of CEUS. Outreach activities include collaborations, workshops, and conference presentations.

2.1. TECHICAL ACTIVITIES

The main technical activities were the analysis of the CEUS database and the development of the Cal-Arch program and website, as well as evaluation of benchmarking methodology.

2.1.1 CEUS Data Analysis

In the initial phase of the project involved obtaining CEUS in SAS data sets from the CEC and performing extensive exploratory analysis of the database. The data were analyzed and converted to the format required for the benchmarking tool. The data used were utility and fuels information, floor area, building type, and zip code/climate zone. A memo describing the processing of data was reviewed by the California Energy Commission (1).

Statistical Weights

The initial conditions of use of CEUS required that statistical weights included in the survey be used, and thus the initial version of the software released used these weights. Both energy and premise weights were supplied. After reviewing the distributions with and without weights, and after much consideration of the suitability of the weights for this application, CEC agreed that the weights were not necessary for the purpose of masking site information.

The reason for having statistical weights in the first place is to extrapolate the sample to the population. Thus, for the PG&E CEUS, the weighted total energy use of the sample would represent the total energy use of the population represented by the sample. The decision was made not to use the weights because there was not evidence that they were valid or necessary our application. First, the weights were developed separately for PG&E CEUS and SCE CEUS, and were developed according to different criteria, sampling stratifications, and for different populations. Hence, when combining information from different surveys it was not clear what the weights represented or if there was any validity for using them in the context of Cal-Arch. Furthermore, they were confusing to users and prevented the inclusion of data from other sources without statistical weights, such as the Non-Residential New Construction Survey (NRNC), Energy Star Buildings Database, and independent datasets such as provided by GSA.

The EUI distributions change greatly when the weights are used. Figure 2.1 below shows the weighted and unweighted distributions for whole-building energy use in offices.

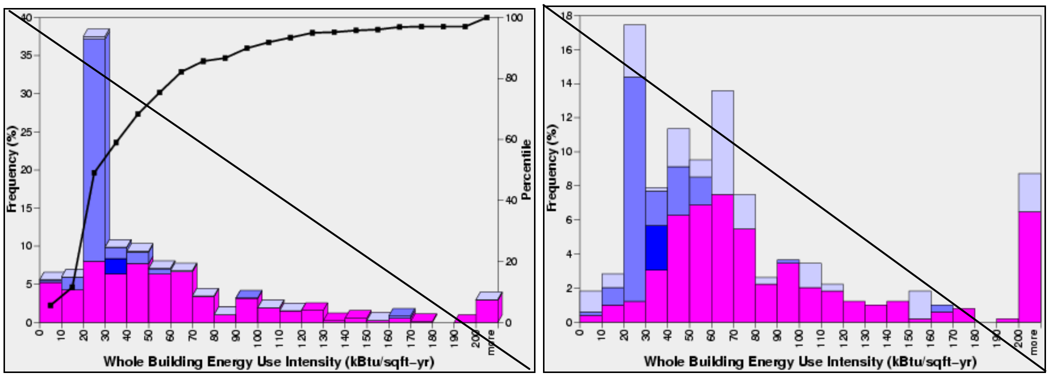

Figure 2.1. Office EUI distribution, weighted and unweighted

2.2.1 Software Development

The Cal-Arch program is based on the existing Arch for U.S. buildings. Arch was duplicated and then modified to create Cal-Arch. Improvements were made to the graphic generation component to increase the speed of the program and functionality modified to meet the specifications of Cal-Arch.

Initial changes included the replacement of the census region parameter with California climate zone and the implementation of statistical weights. The weights were later removed, as discussed in the previous section. By the end of Year 1, a preliminary version of the tool using 1995 PG&E CEUS data was online. At the end of Year 2, a new version was released which included an enhanced appearance and interface, substantial documentation and reference information, and additional feature enhancements. The feature enhancements included the addition of SCE CEUS data, separate graphs and results for gas, electricity, and whole-building energy (gas-electric and all-electric), and additional output statistics.

Software development activities in Year 3 focused on debugging and tweaking in response to feedback. Most significantly the bin calculation algorithm was modified and the application of statistical weights was removed, actions which affect the output distributions and graph appearance. An option was added to select between a frequency histogram and a cumulative frequency histogram as the graphic display was confusing to some users. Links to help information are still present in the output for users who still need assistance understanding the graphs. An xml output capability was also added to Cal-Arch to facilitate automated cgi queries by SiliconEnergy (or anyone else desiring xml output) so that Cal-Arch benchmarking functionality can be provided in their preferred format within their own software environment.

2.3.1 Benchmarking Methods

Cal-Arch provides uses distributional benchmarking as a method of comparison. The distribution of EUIs for comparison buildings is displayed graphically in a histogram and summary statistics are provided for each quartile. The data displayed are actual EUI and are not adjusted for climate or other factor. As part of our analysis we reviewed additional methods and tools. Because gas data were not provided for the SCE CEUS dataset, a procedure to add gas energy-use intensities for each building type within Cal-Arch was considered. Methods considered to develop the gas energy use estimates included DOE-2 simulations, estimates of gas intensities from So. Cal. Gas, or extrapolations from other data sets. Given the available data and budget, satisfactory estimates could not be obtained. Examination of the PG&E dataset showed that there is a large variation in gas EUI within each climate zone and building type so estimates by climate zone would be of little use. Additional advanced benchmarking methods have greater potential for future implementation using 2002 CEUS data. This is described further in the Conclusions and Recommendations section.

EPA Energy Star Analysis

As part of the EPA cost share, Explore Benchmarking Methods for Metric Set, we analyzed additional California CEUS data. The PG&E CEUS data were entered into the EPA Energy Star rating tool for K-12 schools. The 45 locations scored an Energy Star rating at an un-weighted 69% rate and a premise-weighted 87% rate. We are not entirely sure why such a high number of buildings score so well. One factor is that there appears to be a "California Climate Bias" in the Energy Star Rating model. Currently, the models assume that heating degree days (HDD) and cooling degree days (CDD) are consistently correlated throughout the US. As a result of this assumption, the Energy Star model for K-12 schools uses only the HDD. For Census Division 9 (CA, OR, WA, AK & HI) the correlation is not maintained. With a given HDD in California, the Energy Star model assumes a higher CDD and thus predicts that the building needs more cooling energy than the actual CDD. It is expected that the future models for both offices and schools will include both the HDD and CDD terms.

Additional work was done with EPA in regards to energy used by K-12 schools with pools. It was noted that most of the schools with the highest EUIs were those with pools. LBNL developed a simplified "pool correction" method to account for pool energy use which will be incorporated into future Energy Star models (2).

2.2. Outreach Activities

A number of outreach activities have taken place over the course of the project. This includes presentations and discussions at professional meetings and conferences, research and industry collaborations, and public workshops. Table 2.1 lists outreach activities in chronological order.

Table 2.1. Outreach Activities

August 2000	Initial discussions with Honeywell regarding data sharing and collaborations
May 2001	Presentation at Building Energy Analysis seminar at PG&E's Pacific Energy Center

July 2001	Meeting with SiliconEnergy
May 2002	EPA-CEC discussion regarding Energy Star and California buildings
June 2002	ASHRAE meeting
July 2002	Meeting with PG&E Savings by Design Program
August 2002	Presented conference paper and co-moderated informal session at ACEEE Summer Study
September 2002	Presentation to California Emerging Technologies Coordinating Council meeting in San Diego
November 2002	Half-day workshop at PG&E's Pacific Energy Center
March 2003	Presentation at Rebuild America Technology Seminar, SCE Customer Technology Application Center. Cal-Arch brochure completed and distributed at seminar.
May 2003	Presentation at Current Topics in Applied Statistics conference, Cal State Hayward
June 2003	Paper co-authored by LBNL presented at ECEEE Summer Study
June 2003	Tabletop display and demonstration at ACEEE National Conference on Energy Efficiency as a Resource

2.4.2 Workshops and Meetings

The original plan for Cal-Arch included market transformation activities funded by PG&E; however, these funds were not received. Given the growing interest in benchmarking tools, the original market-based plans were revisited in Year 3 and the Year 3 activities were revised to include collaborations with the utilities, including 2 public workshops held in cooperation with PG&E and SCE. In addition, LBNL presented work on Cal-Arch at the September 2002 meeting of the California Emerging Technologies Coordinating Council (ETCC) and discussed California-related benchmarking issues and the potential opportunities provided by the 2002 CEUS. The ETCC is comprised of representatives of PG&E, SCE, SDGE, and CEC.

Two workshops were scheduled in 2002-2003 to present Cal-Arch to public audiences and to obtain feedback through dialog and paper surveys. Results of the surveys and actions taken are discussed in the Outcomes section and are detailed in Appendix B. The first of these workshops was held in November 2002 at the Pacific Energy Center in San Francisco. This was a half-day workshop dedicated solely to benchmarking and to Cal-Arch and was publicized through the Energy Center's calendar and mailing lists. Instead of reproducing this event in Southern California, a one-hour presentation was given as part of a well-attended and received Rebuild America and Southern California Edison technical seminar.

A conference paper titled 'Development of a California Commercial Building Benchmarking Database' was presented at the 2002 ACEEE Summer Study on Energy Efficiency in Buildings. Also at the Summer Study, LBNL collaborated with Doug Gatlin (EPA) and Adam Hinge (Sustainable Energy Partnerships) in the development and moderation of an informal session concerning benchmarking and whole-building rating methods. The well attended meeting brought forward numerous technical and market issues regarding benchmarking. Once conclusion was the need to identify key miscellaneous end-use equipment, perhaps the top 10, that may make a large impact on EUIs.

2.5.2 Industry Collaborations

Opportunities for collaborations with Honeywell and Silicon Energy were explored from the early project stages. The interaction with Honeywell aimed to build on our relationship with the Atrium project and discuss the feasibility of data sharing. The Atrium project has since ceased operation. Our partnership with SiliconEnergy explored university building benchmarking. Silicon Energy is working with several campuses in California, including San Jose State, UC Santa Barbara, USC, and Long Beach State. Karl Brown from CIEE has also been working with the University of California to develop benchmarking methods and has expressed interest in collaborating with the LBNL PIER HPCBS benchmarking work. In addition, SiliconEnergy created functionality for its California customers to query Cal-Arch from within EEM Suite.

2.6.2 Energy Star Building Program

LBNL also worked with CEC and the U.S. Environmental Protection Agency to assess the suitability for promoting the Energy Star Buildings Label within the Flex Your Power campaign. As California buildings seemed to meet labelling criteria in higher percentages relative the national population, CEC was concerned that the wrong message would be sent if the label was promoted. Buildings could receive the label even if there additional measures that could be taken to reduce energy consumption. Analysis conducted by LBNL and EPA indicated higher scores on average among California offices; however, a discrepency between CEUS and CBECS left the difference in scores for schools unresolved.

EPA also provided supplementary funds for analysis related to the Energy Star models for offices and schools as discussed in Section 2.1.1. CEUS Data Analysis.

2.7.2 Research Collaboration

LBNL provided Ken Gellespie and ASHRAE TC 9.6 (Systems Energy Utilization) feedback on a work statement to test benchmarking tools at the June 2002 Annual ASHRAE Meeting. Cal-Arch will be included in the tools that will be considered for testing.

In 2003, LBNL collaborated on a conference paper with Bernard Aebischer of the Centre for Energy Policy and Economics in Zurich, Switzerland on energy benchmarks for restaurants and data centers. Using PG&E CEUS data, different metrics for each restaurant type (table service, fast food/self service, and bar/tavern/nightclub) were analyzed and compared with results from other regions. The metrics compared were energy use per square meter, energy use per meal, and energy use per seat. This project also involved researchers from France, Belgium, and Japan.

In December 2002, LBNL met with Helen Mulligan from the UC Berkeley School of Environmental Design. She is a visiting researcher from the UK interested in data to characterize the commercial sector. We plan to incorporate some of her research interests into the Cal-Arch project.

2.8.2 CEC and PIER Contract Linkages

LBNL provided assistance to Schiller Associates and Pacific Northwest National Laboratory in acquiring and managing CEUS data for use in their PIER work.

LBNL has been working on benchmarking issues that have involved extensive discussion with NBI and their work with the CEC and EPA on the relationship between code and Energy Star scores. Though this is not directly related to the PIER buildings programs, it is related to CEC's work with NBI and code. (See the ACEEE 2002 paper by Jeff Johnson). LBNL also corresponded with Daryl Mills at the CEC who expressed interest in LBNL's analysis of school energy use data. LBNL has also worked with other Collaborative for High Performance Schools (CHPS) partners including Greg Ander and Charles Eley and was involved in discussion between EPA and CEC regarding the Energy Star buildings label and California (Section 2.6.2).

2.9.2 Technical Advisory Group

3. Outcomes

3.1. Cal-Arch Software

Cal-Arch can be used from any web browser on most operating systems by pointing to http://poet.lbl.gov/cal-arch/. The software functionality is described here. User help information and reference material are also included on the user-friendly website.

3.1.1 User Interface

Cal-Arch is intended to be a simple tool that is quick and easy to use, and thus a minimum number of user inputs are requested. Figure 3.1 shows a snapshot of the user input page. The only inputs requested are building type, zip code, floor area, energy consumption, site/source selection and graph type selection. Users who do not have their own data on hand can still use the tool to browse EUI distributions according to the search criteria (building type, floor area, climate zone). Information on each input field is given below.

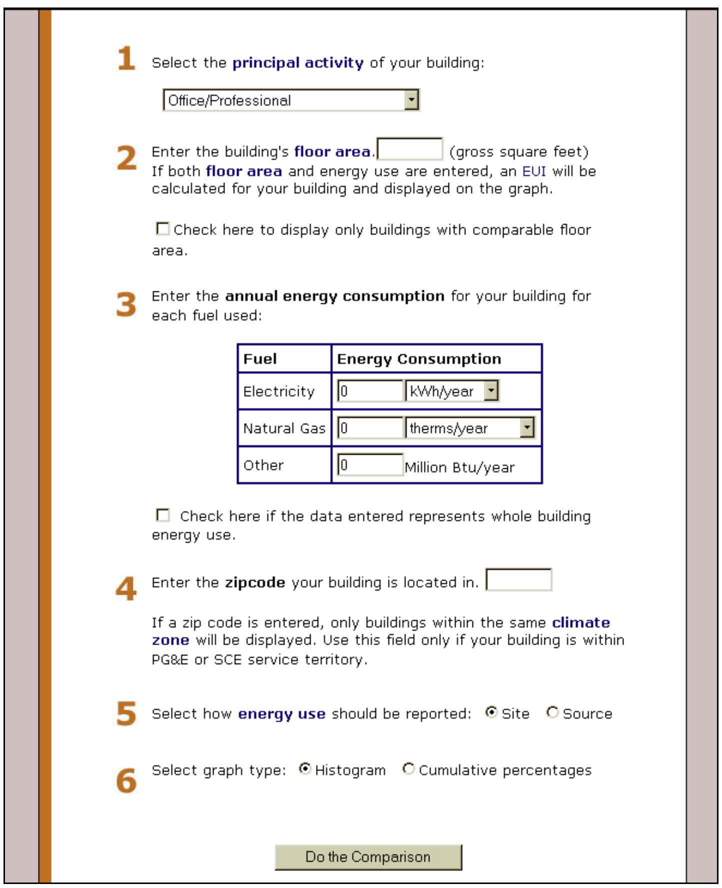

Figure 3.1. Cal-Arch Input Page

Building Type

The building type is defined to be the building function occupying the most floor area. The categories for building type in Cal-Arch have been designed to correspond roughly to CBECS categories. This was done for consistency, familiarity, and to increase sample sizes for each category. Table 3.1 shows how CEUS categories were mapped to CBECS categories for use in Cal-Arch. Title 24 categories are also shown as the Non-Residential New Construction Survey (NRNC) has also been considered for inclusion in the Cal-Arch database.

Table 3.1. Building Type Correspondence

CBECS Category	CEUS Category	Title 24 (NRNC)
Agricultural	Agricultural	
Education	Daycare Elementary/Secondary College Vocational or Trade School	School
Enclosed Shopping/ Mall	Shop in Enclosed Mall	
Food Sales	Supermarket Convenience Other Food Store	Grocery Store
Food Services (Restaurant)	Fast Food or Self Service Table Service Bar/Tavern/Club/Other	Restaurant
Health Care (Inpatient)	Hospital	
Health Care (Outpatient)	Medical Clinic/Outpatient Care	Medical Clinic
Industrial Processing/Mfr	Assembly/Light Med/Heavy Food/Beverage Processor	
Lodging (Hotel/Motel/Dorm)	Hotel Motel Resort	Hotels/Motels
Nursing Home	Nursing Home	
Office/Professional	Administration Financial/Legal Insurance/Real Other Office	Office
Public Assembly	Recreation or Other Public Assembly	Religious, Auditorium, Theater Community Center Gymnasium, Library
Public Order & Safety		Fire/Police/Jail
Religious Worship	Church	Religious, Auditorium
Retail (except mall)	Department/Variety Other Retail	Retail & Wholesale
Service (except food)	Gas Repair/Non-Auto Other Service Shop	
Warehouse (non-refrigerated)	Warehouse (non-refrigerated)	C&I Storage
Warehouse (refrigerated)	Warehouse (refrigerated)	C&I Storage

Floor Area

Gross floor area is requested from the user in order to calculate their EUI and it is also one of the variables that Cal-Arch allows you to filter the comparison buildings with. In CEUS, the survey unit is a “premise” rather than a “building”. A premise may be all or part of a building, and sometimes more than one building, but is usually a single utility customer billing account.

Climate Zone

The California Energy Commission recognizes sixteen climate zones in California. As CEUS contains zip codes, these are easily mapped to climate zones. For sample size purposes it is advantageous to narrow the climate zones to four categories as illustrated in Figure 3.1.

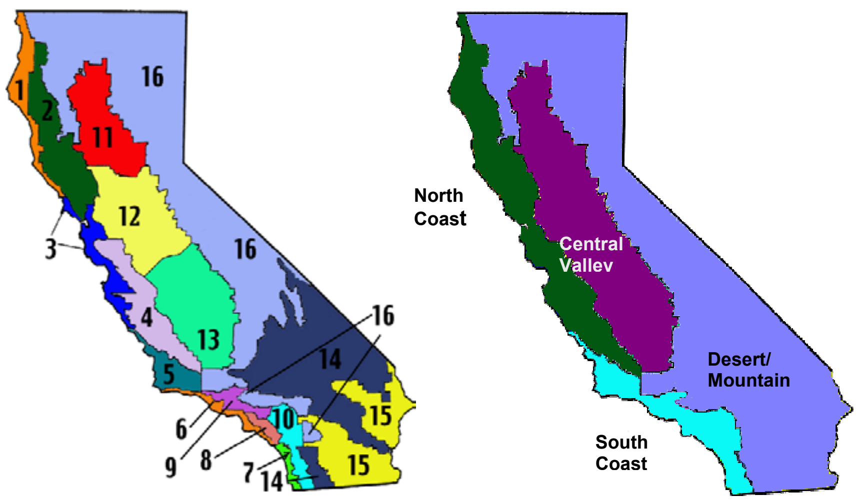

Figure 3.1. Climate Zones

Whole Building Energy

Annual energy use data used to calculate EUI is usually obtained from utility billing data. Billing data were included in CEUS; however, for SCE CEUS only electric bills were provided and for PG&E CEUS, only gas and electric. Hence, whole-building energy use is not available for all buildings in CEUS. Part of the analysis of CEUS was to determine which fuels are used by each site and to assess whether the energy use reported represents ‘whole-building’ energy. Especially important in benchmarking electricity use is determining which building are all electric. The electric EUI for an all-electric building represents whole-building energy use while the electric EUI of a building with gas heat does not.

Site/Source Energy

An option is provided to display results in units of source energy or site energy. Site energy is what most users are familiar with as it is the amount of energy which they use and are billed for. Source energy accounting is used to make comparisons of the true impact of consumption as it accounts for losses in transmission and generation. The site-to-source conversion factors used are 2.7 for electricity (3) and 1 for natural gas. The actual values vary by fuel type and location.

Graph Type

Users may select to have frequency histograms or cumulative frequency histograms included in their output as shown in Figure 3.2.

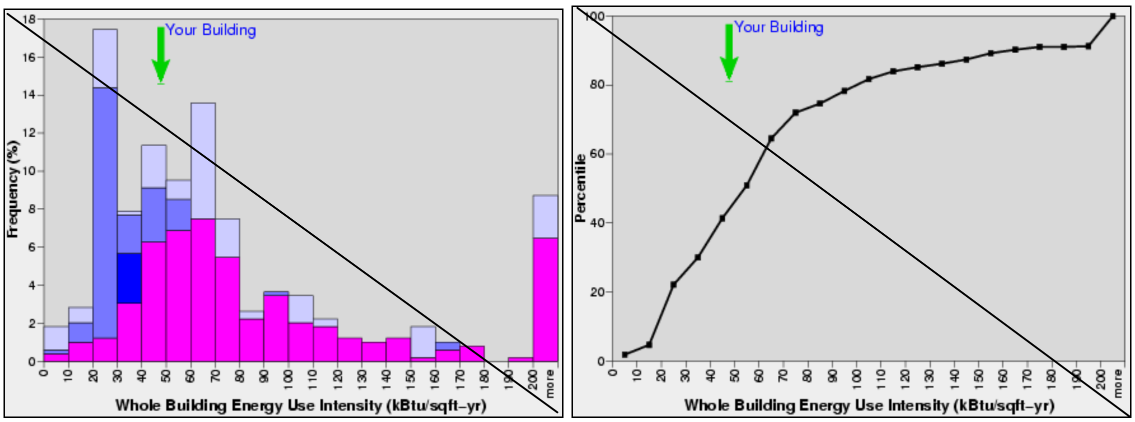

Figure 3.2. Graph Types

Results

Depending upon the inputs entered, the Cal-Arch database is queried and the results are displayed as a histogram displayed with statistics describing the comparison buildings and the user's EUI. Additional information is provided to aid in the interpretation of the results as well as links to further information about the data sources and other benchmarking tools. Figure 3.3 shows a sample histogram and summary for whole-building energy use. Similar results are produced for electricity and gas use comparisons. Figure 3.4 shows an example of the legend and additional information provided with the output.

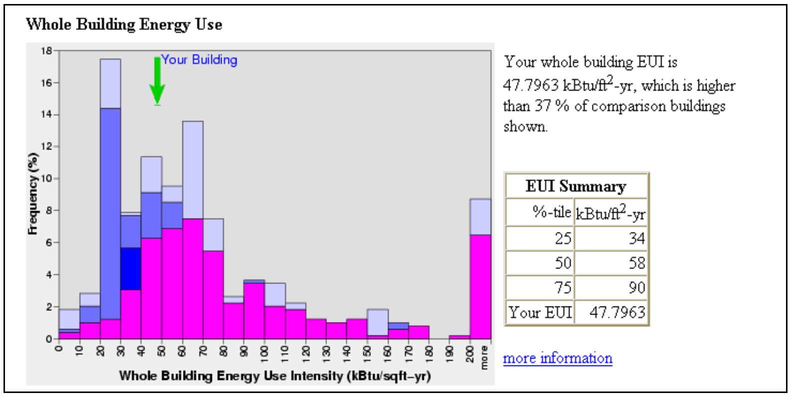

Figure 3.3. Output Display - Summary

LEGEND

Bar Color	Data Source	For further information:
	PGE_CEUS	PG&E CEUS
	SCE95L	1995 SCE Low-Res CEUS
	SCE92L	1992 SCE Low-Res CEUS
	SCE92H	1992 SCE High-Res CEUS

Description of Comparison Buildings

For this field:	You entered:	Comparison Buildings
Building Type	Office/Professional	Office/Professional
Zip Code	Not entered	All climate zones are shown
Floor Area	50,000 ft²	
Filter by area?	No	Buildings of all sizes are shown
Site/Source	Site	Results are displayed as site energy use

Number of buildings on graphs:

Whole Bldg	Electric	Gas
267	423	210

Continue to Interpret Results page for additional information about these results.

Was this helpful? Please take our **SURVEY**

Figure 3.4. Output Display - Legend

3.2. *TECHNICAL REPORTS*

Several reports and technical memoranda were produced during this project, many of them specific project deliverables. Appendix B lists project deliverables and their anticipated and actual dates delivered.

- The first technical report was a software specification for Cal-Arch completed in January 2001 (4). Some revisions to the specification were made in the Year 2 Final Report to accommodate the addition of two public workshops.

- A technical report on existing benchmarking methods and tools was submitted in July 2001 as a Year 1 deliverable (5).

- The paper "Development of a California Commercial Building Energy Benchmarking Database" discussing the development of CEUS data for benchmarking and the benefits of regional benchmarking was presented at 2002 ACEEE Summer Study on Energy Efficiency in Buildings in August (6).

- The Cal-Arch brochure was the first in a series of HPCBS brochures (7). It was completed in March 2003 and was distributed to attendees of the Rebuild America Technology Seminar in Irwindale, CA on March 13th.

- LBNL contributed to a paper titled "Energy efficiency indicators for high electric-load buildings" which was presented at the 2003 European Council for an Energy Efficient Economy Summer Study in France by Bernard Aebischer of the Centre for Energy Policy and Economics in Zurich, Switzerland (8).

3.3. Future Plans

A fourth project phase has been approved which will primarily focus on outreach activities and planning for a more a potential future Cal-Arch which would incorporate 2002 CEUS and more advanced functionality. This project will have 3 primary components:

- Additional research and analysis of K-12 schools benchmarking, partnering with the California High Performance Schools Collaborative (CHPS)

- Collaboration with Energy Information System vendors to embed Cal-Arch directly in their tools

- Planning activities to support the development of a more advanced Cal-Arch to build on the Dr. CEUS database being developed by RER for the California Energy Commission.

4. Conclusions and Recommendations

Building energy benchmarking is a valuable step in many energy efficiency projects, whether new construction, retrofit, tune-ups, or ongoing operations analysis. Design engineers, building owners, and operators often seek information to understand how their building compares with others.

The web-based benchmarking component of the HPCBS Program has focused on the development of Cal-Arch, a tool for benchmarking energy use in California buildings. The primary source of data for this tool is the 1992-1995 CEUS. The interest in this type of program has been demonstrated over the course of the project, through meetings, presentations, and workshops, with utilities, industry partners, and target users (building managers, energy analysts, etc.).

This tool will cease to be useful if the data are not kept up to date. The release of 2002 CEUS data will present an opportunity to greatly enhance the usefulness of this tool and to integrate more advanced benchmarking methods.

5. Acknowledgments

Other LBNL staff who have contributed to this project include Brian Smith, Krister Udd, Alan Meier, Bruce Nordman, Norman Bourassa, and Mithra Moezzi. We are also grateful to Martha Brook and Lynn Marshall (California Energy Commission), Bob Rose and Tom Hicks (Environmental Protection Agency), Anne McCormick, Sam Cohen, and Robert Sonderegger (SiliconEnergy). This work was supported by California Energy Commission Public Interest Energy Research Program and by the Assistant Secretary for Energy Efficiency and Renewable Energy, Office of Building Technology, State and Community Programs of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

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Appendix A. Milestones and Deliverables

Description	Start Date		Due Date	
	Planned	Actual	Planned	Actual
Technical memorandum on the evaluation of California data sets	7/15/00	8/1/00	7/14/01	7/14/01
Technical memorandum on benchmarking methodologies	7/15/00	8/1/00	7/14/01	7/14/01
Specifications for modifications for existing benchmarking software to include California data sets	7/15/00	8/1/00	2/10/01	2/10/01
Operational web-based benchmarking tool with California data sets	7/15/00	8/1/00	7/14/01	7/14/01
Enhanced benchmarking database	7/15/01	7/15/01	7/01/02	
Final benchmarking tool and report evaluating benchmarking with advanced normalization procedures	7/15/02		7/14/03	

Appendix B. Survey Responses

To date, 20 long surveys and 50 short surveys have been completed. Five of the long surveys were completed online and fifteen at the workshop on November 21st. One person completed both online and paper versions. The only difference between the two is that on paper many people chose multiple options where they were given; whereas on computer they are restricted to one choice. According to Ryan Stroupe, 17 people attended the workshop, so 15 responses represents a very high response rate. One non-responder is known to have completed the online version. The short surveys were administered at the March 13th workshop in Southern California.

A companion spreadsheet contains complete responses for each survey. This appendix summarizes results by question.

B.1 Summary of Responses

B.1.1 Long Survey

General Information

1. What is your job/role:

The most common response was Other (8) followed by Service Provider (7) and Owner/Manager (3). The job titles included under Other included Consultant, Systems Engineer, Electric Utility Energy Analyst, Consulting Engineering/Manufacturer, Business Dev (marketing) for large commercial projects, Energy Engineer (2), Energy Consultant (2) , and Major Account Manager (PG&E).

2. Types of buildings you deal with mostly:

Most paper respondents selected multiple options. The most common response was Office (13). Others were Retail (7), Medical (5), and Education (7). Responses to Other included Residential (2); Fed. Govt, Labs, etc; Industrial, Hotels/Restaurants, Fitness, and Manufacturing, All of the Above (2).

3. Typical size of buildings you deal with:

Again, several respondents responded to multiple categories. The total tally was

< 10,000 sqft (5), 10-50,000 sqft (8), 50-250,000 sqft (10), >250,000 (7).

Usage

4. Have you used Cal-Arch before today? **5** Yes **14** No **1** NR

5. Have you used Energy Star Portfolio Manager? **4** Yes **15** No **1** NR

6. Have you applied for an Energy Star Buildings Label?

Three responders have applied for Energy Star Labels. One reported 20+ buildings applied and receiving the label; another, ~45 received out of ~50 applying; and the last, 1 of 1.

7. Have you used any other tools for benchmarking whole building energy use? Please list any other tools you have used:

Eight people listed tools they had used. Of these, two had answered No to the first part of the question. The tools listed include Arch, CBECS, Emcor Energy Edge, Equest, LEEDS, T-24, EnergyPro (DOE-2), Energy Star (perhaps should add this to Q.5), Excel spreadsheets, BOMA, Emcor (internal tool), and Honewell's MyFacility website.

8. How often do you use or plan to use benchmarking tools?

Nine (9) answered Once in a while (or equivalent); three (3) were about once a month, and four (4) were about once a week. One person answered "would like to start" and three did not respond.

9. How will you/your customers use Cal-Arch?

Sixteen (16) people responded to this question. Of these, two (2) were uncertain. Of the remainder, six (6) mentioned preliminary audit/evaluation; two (2) mentioned reporting and communication; the remaining comments included retrofit energy savings, incentive programs, evaluations for design, screening, and comparison. See spreadsheet for complete responses.

10. How do you expect it to benefit you or your customers?

Thirteen (13) people answered this question. Most of these referred to relative comparisons, demonstration of opportunity, targeting buildings, etc. One mentioned marketing image. Some were more specific than others; see spreadsheet for complete responses.

Inputs

11. Are the instructions clear?

16 Yes **0** No **3** NR **1** mostly

12. Is the requested information easy assemble? **15** Yes **1** No **4** NR

Are the fields for querying (building type, climate zone, etc) sufficient for finding similar buildings? **12** Yes **4** No **4** NR

One write-in comment suggested "instead of current display, group filters together".

13. How important are the following criteria for a benchmarking tool?

Five (5) people answered Very Important for each field listed and two (2) answered Important for each. Ten (10) had mixed responses and three (3) did not respond at all.

Criteria	Unim-portant	Don't care	Important	Very Important	No Response
Building Type			5	12	3
Floor Area			5	12	3
Climate Zone			5	12	3
Building Age			10	7	3
Heating Type		1	9	7	3
Cooling Type		1	9	7	3
% Heated		2	7	7	4
% Cooled		2	8	6	4

14. What additional characteristics (search fields) would be useful ?

Seven (9) people responded to this question. Four (4) mentioned hours of operation or occupancy and one (1) mentioned system type. Also requested were prorations for mixed-use buildings, breakdown of gas usage for water heating, and HDD/CDD.

15. Additional comments on input fields and input page:

There were three (3) additional comments. One person was interested in accounting for district steam and gas cooling. One person suggested that filters should be able to be activated and deactivated after each iteration (I think this is more or less the case). The last was interested in an interface similar to portfolio manager, ie, tracking over time.

Output

16. Are the graphical displays useful to you? **14** Yes **2** No **5** NR

17. Are the summary statistics useful to you? **13** Yes **2** No **6** NR

One Yes response was qualified by "but less so" presumably relative to the graphical display. One No response wrote in "need to explain".

18. Do the results seem plausible? **12** Yes **1** No **6** NR

The one No response was the online survey taken by the person who repeated it on paper (I don't know which paper response is his). So he either changed his mind or declined to repeat his statement. Interestingly enough, the results on the whole-building graph changed the day after this event when Brian fixed an error in the whole-building energy calculation.

19. Any additional comments on the graphical displays and summary statistics:

20. Please provide any additional comments about the results, their usefulness, and any action you might take based on them

21. Please provide any additional comments about the Cal-Arch tool and website

In retrospect some of these questions are redundant and in some places comments appear to be answers to different questions. In any case, the primary intent of the survey was to illicit comments.

Ten (10) people responded to at least one of these questions; most only to one, so I'll summarize the responses all at once. Three (3) were generic or uncertain. Three (3) expressed concerns with the limitations due to sample size and non-whole building energy use. One person pointed out a bug in the program, which was subsquently fixed.

Six (6) offered specific suggestions for improvement: first, to give the real energy costs, carbon emissions, etc as summary outputs. To some extent we have this with the Source energy option, but we could hard-wire it to give both, but not just in kBtu but in lbs of coal or emissions, etc.; second, to make it more friendly to facility managers and property managers; third, to include cost information; fourth, to include energy standards, mentioned twice; and fifth, to include max, min, mean, and standard deviation, which I have explained my disagreement due to the skewness of the EUI distributions.

Contact

22. Which electric utility service territory are most of your buildings located in?

12 PG&E   SCE   SDGE

1 SMUD   **1** LADWP   Other Calif.

2 Other US   Outside US   **1** Varies

23. Would you be willing to share data on one or more buildings? **5** Yes **14** No/NR

24. If so, or you are otherwise open to future contact, please provide your contact info.

Six people gave names and contact information

25. Please add any additional comments you may have.

Five (5) people had some extra comment, in this field or outside of any specific field. Two were generic. One was mostly illegible but seemed to say something about importance of speed and ease of use. Another appeared to be an incomplete thought related to the "team integration" approach of LEEDS and communicating information to different parties (owner, users, architects, etc.). The last expressed the desire for similar functionality in a tool for all of the U.S. or North America.

B.1.2. Short Survey

General Information

1. What is your job/role?

The most common response was Other (21) followed by Owner/Manager (15) and Service Provider (11), Operator (5), and Manufacturer (3). The roles listed under Other included architects (8), utilities (3), and energy manager/analyst (3). Total responses: 49

2. Types of buildings you deal with mostly:

The most common response was Office (22). Others were Retail (13), Medical (16), Education (10), and Other (19). Responses to Other included Industrial/Manufacturing/Lab (8) and All/Varied (3). Total responses: 49

3. What benchmarking tools have you used before?

Energy-10	1
Energy Cap	1
Title 24	1
DOE-2	1
Other analysis	11
Utility bills	2
SCE resources	1
Energy Star	1

4. How often do you plan to use benchmarking tools?

Never	7
Occasionally	26
Regularly	12

Total Responses: 45

5. How will you or your customers benefit?

Comparisons	Compare energy use & plan changes of equip or construction	8
Design	Specify through design process & advise clients w/existing bldgs	5
Targets	Look for potential energy savings & maintenance tasks, set goals	5
Lacking	Would like to have a natl tool, does not apply to my facility type	3
Programs	Selection programs, LEED documentation	2
Money	Save $, To check energy budgets	2
Glazing	Look for glazing, Deltas	1
Service	Provide better service for our customers	1

Total Responses: 27

6. What are the most important selection criteria?

Note: Leaving this open-ended resulted in some interesting responses; apparently some people misunderstood the question.

Building Type	17
Size	15
HVAC	8
Location, Climate	7
Age	7
Building Envelope/Contruction	5
Shape, Style, Orientation, Shading	5
Lighting Requirements or Type	4
Window, Roof Construction	4
Occupancy	4
Heating load, PCs, electronic equipment	3
Daylighting	1
Energy Source	1
Schedule	1
Suburban/City	1

Total Responses: 30

7. Is Cal-Arch easy to use?

Yes	34
No	3
Maybe/Other	1

Total Responses: 38

8. Are the graphics and summary statistics useful?

Yes	25
No	7
Maybe/Other	2

Total Responses: 34

9. Is Cal-Arch useful to you in its current form?

Yes	17
No	15
Maybe/Other	3

Total Responses: 35

10. Will the addition of more Southern California data make it more useful?

Yes	37
No	2
Maybe/Other	1

Total Responses: 40

11. Are you willing to share data on one or more buildings?

Yes	20

12. Contact Info

    Total Responses: 13

13. Additional Comments

Thanks/Good Presentation	4
Will try the program	3
Other	2

Total Responses: 9

B.2 RESPONSE TO FEEDBACK

The following are key points that arose during the discussion at the November workshop:

1. Minimum data set. For some queries, few or no buildings will be returned, particularly if the number of query fields is increased. So the suggestion is that we define a minimum number of buildings that must be returned in order for results to be generated.

   A five-site minimum was implemented in tandem with the removal of weights for masking purposes.

2. Colors. There may be better variables that could be represented by color rather than data source.

   This should be considered in future implementations.

3. Weighting. As could be expected, the use of weights is initially confusing, particularly as the weighted number of buildings is given in the legend (should be removed) before the table at the end of the results summarizing weighted and unweighted numbers.

   The use of weights in Cal-Arch has been removed and no references to weights remain in the output.

4. Important attributes. The hours of operation has been the characteristic of energy most often mentioned. Vintage is another important attribute.

   Information on additional key attributes should be considered for future implementation.

5. Graphing methods. Some people like the current method; others prefer simpler graphics. An option to choose between frequency histogram, cumulative frequency histogram, or both (current method) would be easy to implement.

   Users now have the option to choose between frequency or cumulative frequency histograms.

6. Targets. The current results produced by Cal-Arch are interesting but a little too fuzzy for some people. We do not tell them if they are efficient or not. Many people indicated they would like to compare to "best" buildings, standards, etc.

   We do not feel it is appropriate in this context to say whether or not a building is efficient; however, some assistance in interpretation is provided. Incorporation of published benchmarks could be included in the future if they are clearly defined and do not confuse the results. A future Cal-Arch based on 2002 CEUS data could be used to provide more advanced information with simulated results.

7. End uses. We have noted in the past, particularly in our schools analyses, that often the high EUIs correspond to buildings with more end uses. For example, pools were present in most of the schools with high EUIs.

   This is a complicated issue which we have explored in our discussions with Energy Star and which is discussed briefly in our 2002 ACEEE paper.

Appendix C. Electronic Attachments

The program underlying Cal-Arch and associated documents are archived in the HPCBS internal website under Task 2.1.1. The following are included:

(more detail to come)

- Program files & documentation
- SAS files
- Surveys, response tally spreadsheet
- ECEEE paper, brochure, other non-deliverable publications
- Presentations

California Energy Commission
Public Interest Energy Research Program

HPCBS # E2P21T3c

HPCBS

High Performance Commercial Building Systems

School Energy Use Benchmarking and Monitoring in the West Contra Costa Unified School District

Element 2 - Life-Cycle Tools
Project 2.1 - Benchmarking and Performance Metrics
Task 2.1.1 - Web-Based Benchmarking

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Massachusetts Institute of Technology
August, 2002

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School Energy Use Benchmarking and Monitoring in the West Contra Costa Unified School District

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August 2, 2002

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West Contra Costa Unified School District

The West Contra Costa Unified School District (WCCUSD) is comprised of sixty-three schools, located in seven cities (El Cerrito, El Sobrante, Hercules, Kensington, Pinole, Richmond, and San Pablo) of Contra Costa County. Table 1 presents the schools types in the WCCUSD.

Table 1 *WCCUSD School Types.*

School Type	Number of Schools
Elementary Schools	39
Middle Schools	6
High Schools	6
Alternative Schools	10
Special Education Schools	2

Contra Costa County is located on the northeastern San Francisco Bay area (Figure 1). Some climatic and geographic features of the region serviced by the WCCUSD are as follow:

- N37° 54’ to N38° 01’N latitude and W122° 17’ to W122° 23’ longitude.
- Altitude varies from sea level to approximately 400ft.
- The minimum average and maximum average temperatures are 40°F and 76°F respectively. Absolute maximum and minimum recorded temperatures in the last 5 years are 30°F and 106°F.

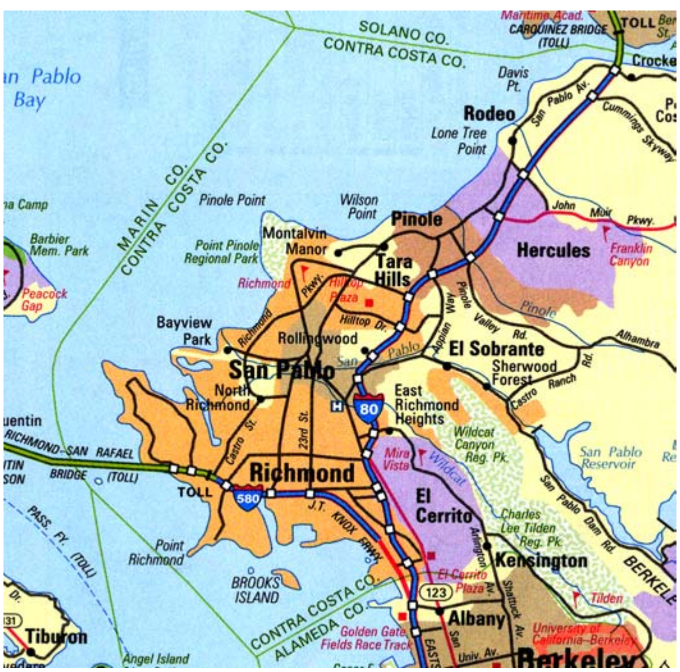

Figure 1 *The Western part of Contra Costa County*

A set of benchmarking tools for school energy consumption is being developed, using energy consumption data from schools in the WCCUSD. Data from thirty-nine elementary schools, five middle schools, and five high schools are being used. Alternative and special education schools are not considered in the study. Energy sources for the WCCUSD schools are electricity and natural gas.

Pacific Gas and Electric Company (PG&E) and the WCCUSD facilities office provided annual (1999-2000) electric and gas consumption records. Energy figures together with school statistics such as student population and density, school schedules, and physical building features such as construction area and equipment are factors involved in the benchmarking analysis of energy consumption.

General School Descriptions

Basic school statistics that were factors in our analysis are presented in Table 2. The typical WCCUSD elementary school has a floor area of approximately 43,000 square feet with an average enrollment of 500 students. In comparison, the typical middle school has an area of approximately 122,000 square feet and an enrollment of about 1000 students, while the average high school has an area of approximately 180,000 square feet and an enrollment of 1,500 students. A graphical comparison of the schools building areas is presented in Figure 2. The enrollment figures comparison is shown in Figure 3.

Table 2 *Basic School Characteristic Statistics.*

	Construction Area (ft2)			Student Population		
	Elementary	**Middle**	**High**	**Elementary**	**Middle**	**High**
Average	43,690	122,530	185,657	499	1,092	1,537
Median	41,742	125,000	177,762	463	1,088	1,438
Maximum	121,086	158,682	226,510	957	1,283	2,167
Minimum	22,858	78,313	160,915	289	953	1,026
Std. Deviation	15,724	28,673	25,073	149	121	417

In general elementary schools are smaller in size and enrollment than middle and high schools, with the exception of Downer Elementary School, which has an area of 121,000 square feet with 957 students.

It is interesting to note that even though the middle and highs schools are larger than the elementary schools, both in physical size and enrollment, their student densities are similar if not smaller (higher area per capita) than elementary schools. Figure 4 presents the student densities for the WCCUSD schools expressed, for convenience, as floor area per student. A higher number indicates a lower density and vice versa.

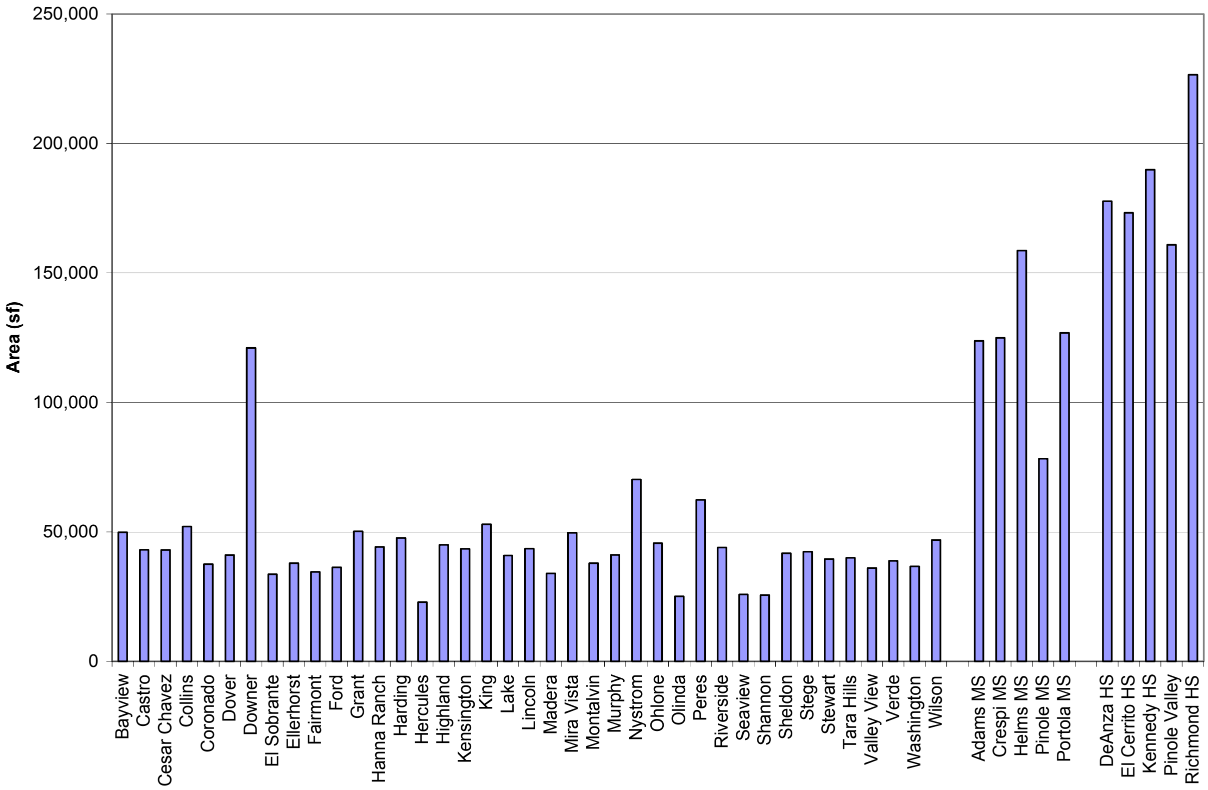

Figure 2 *WCCUSD Schools Building Areas.*

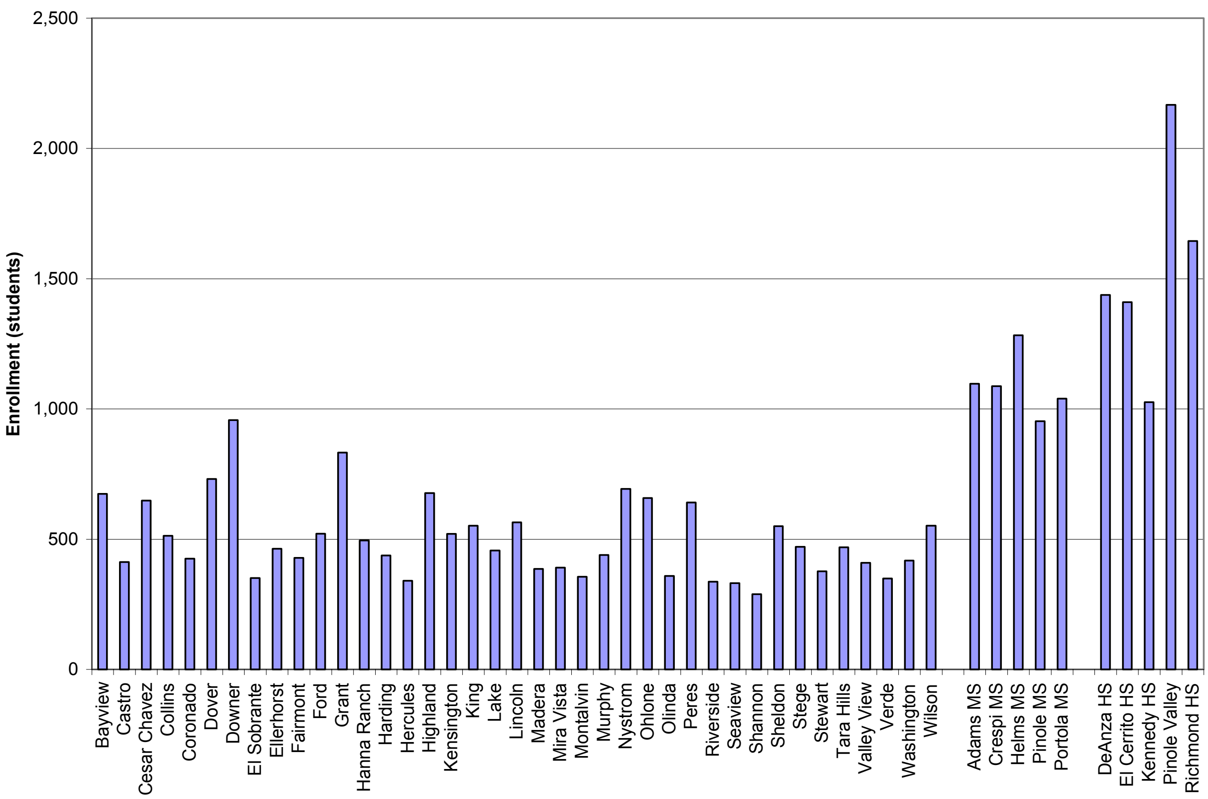

Figure 3 *WCCUSD Schools Enrollment.*

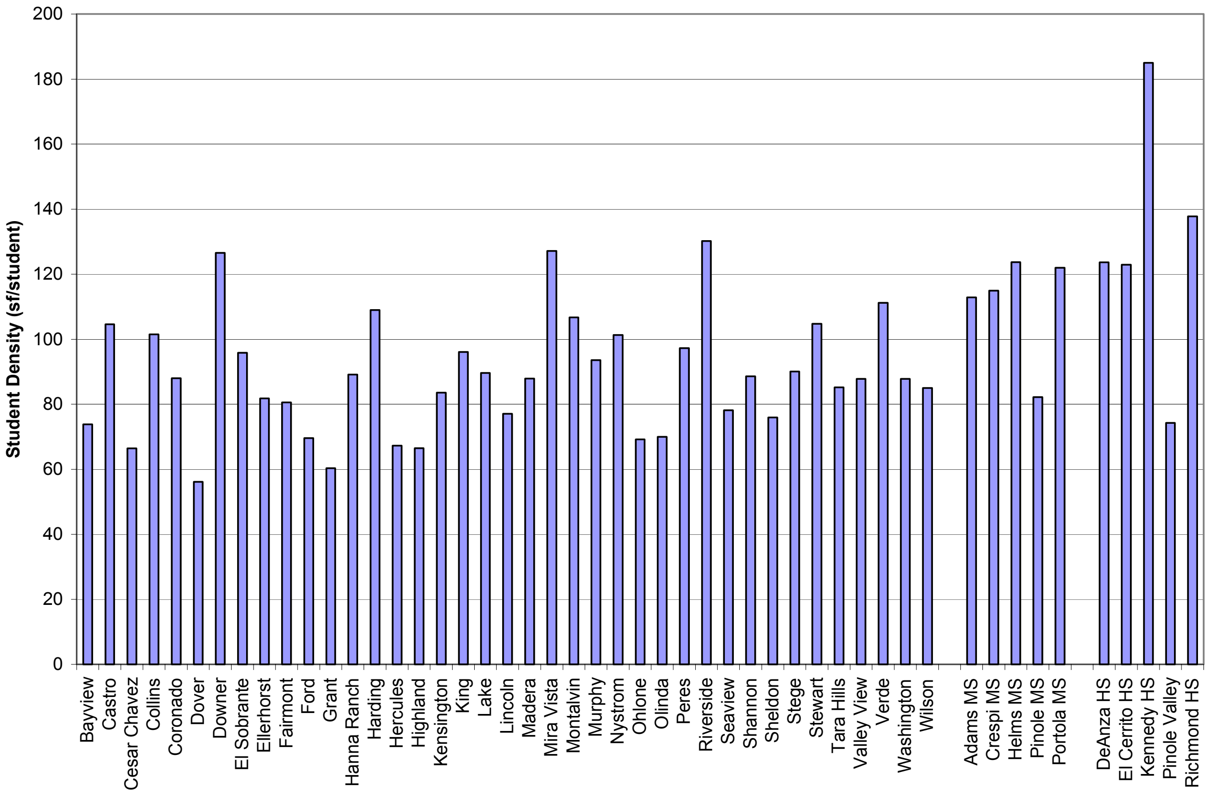

Figure 4 *WCCUSD Schools Student Density.*

Annual Energy Consumption Analysis

Energy consumption analysis for the schools was performed for both sources of energy in the schools, natural gas and electricity, and their combined total in terms of absolute annual values (energy/year) as well as in relative terms (energy/area and energy/student). Additionally, the ENERGY STAR® For Schools benchmarking tools developed by the Environmental Protection Agency (EPA) and the US Department of Energy (DOE) and available on the World Wide Web (http://www.energystar.gov) were used to rate the schools in order to compare the results of the energy analysis performed on the school data.

Absolute Energy Consumption

Absolute energy consumption (Figure 5) of the middle and high schools is greater than the energy consumption of elementary schools, with the exception of *Downer Elementary*, which has energy consumption greater than the middle schools and similar to the high schools. The percentage contribution of the two energy sources utilized in the schools is presented in Figure 6. The basic statistics for the electric energy contribution to the total school energy utilization are presented in Table 3.

Elementary schools rely mainly on natural gas as the energy source, with the exception of *Ohlone Elementary* whose main source of energy (96%) is electricity. The extremely high ratio of electricity to natural gas utilization at *Ohlone* is due to the school's being completely air-conditioned, and the equipment operating on electricity both during the cooling and heating season. Other elementary schools with a high ratio of electricity to natural gas use are at least partially air-conditioned, but the heating equipment is gas fired.

The percentage of electric energy used at the middle schools is lower than in the elementary and high schools. The low ratio of electricity to natural gas use at the middle schools can be explained by the fact that they are not air-conditioned, with the exception of *Pinole Middle* that has partial air conditioning, and heating is provided by natural gas.

Table 3 *Schools Electricity Contribution Statistics.*

	Elementary	Middle	High	All
Average	44%	36%	52%	44%
Median	40%	30%	50%	40%
Maximum	96%	61%	71%	96%
Minimum	18%	27%	32%	18%
Std. Dev.	17%	14%	14%	17%

The fraction of electric energy used at the WCCUSD high schools is similar to the fraction of natural gas energy utilized. The electric fraction is greater than in the middle and elementary schools as a group. Further knowledge of the high school physical equipment is needed in order to provide a good explanation for the approximately equal amounts of electric and gas used.

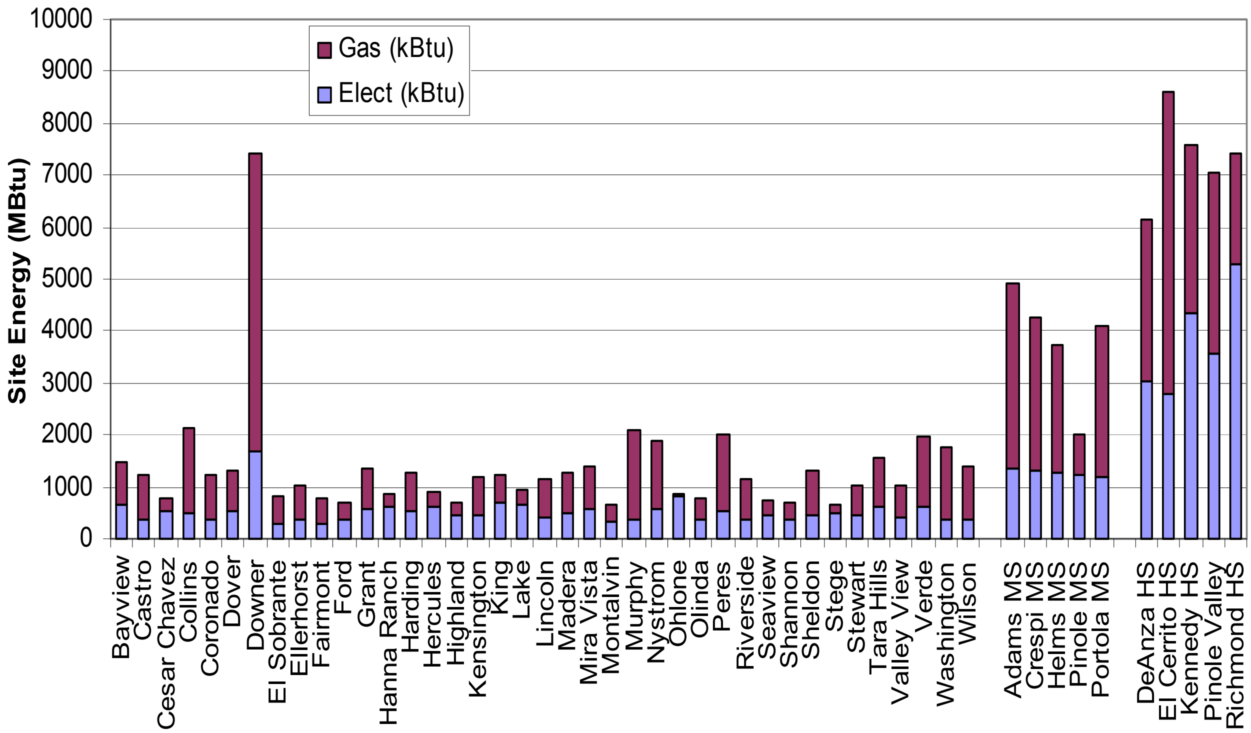

Figure 5 *WCCUSD Schools Absolute Energy Consumption.*

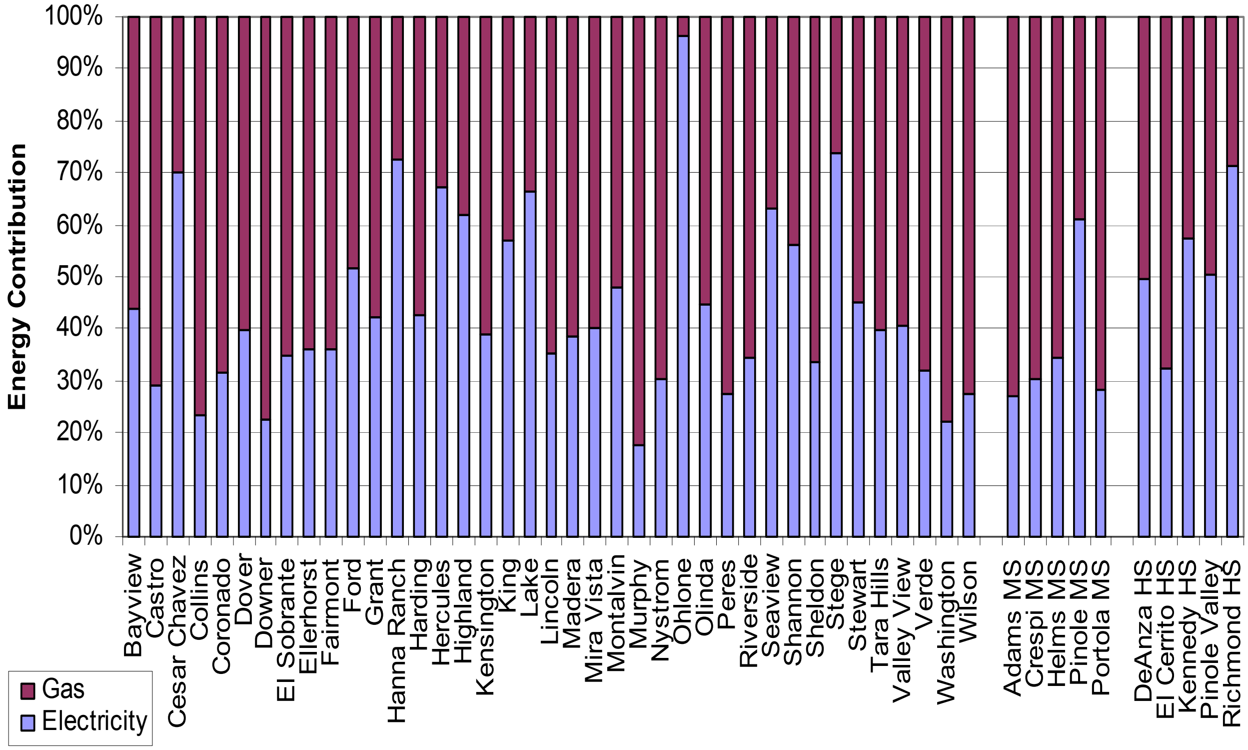

Figure 6 *Percentage Energy Contributions of Electricity and Natural Gas.*

To gain an additional perspective to the problem, the energy cost is also analyzed both in absolute and relative terms. Energy cost for the WCCUSD schools is presented in Figure 7. It can be seen that the total energy cost follows the same trend as the total energy consumption at the schools. Energy cost is the greatest for the high schools, followed by the middle and elementary schools.

Cost contribution for the different energy sources, however does not follow the energy utilization contribution trends presented previously. It can be seen in Figure 8, and in the statistics presented in Table 4, that even though electricity accounts for less than 45% of the total energy use at the schools, in economic terms it accounts for more than 77% of the total annual cost of energy in the district schools. Electricity has a higher cost per site energy unit than natural gas, which explains the greater contribution of electricity to the energy cost in the schools.

Table 4 *Schools Electricity Cost Contribution Statistics*

	Elementary	**Middle**	**High**	**All**
Average	76%	72%	82%	77%
Median	77%	66%	83%	77%
Maximum	99%	88%	93%	99%
Minimum	51%	62%	67%	51%
Std. Dev.	11%	11%	9%	11%

The energy consumption and cost data for the studied schools are presented in Appendix B.

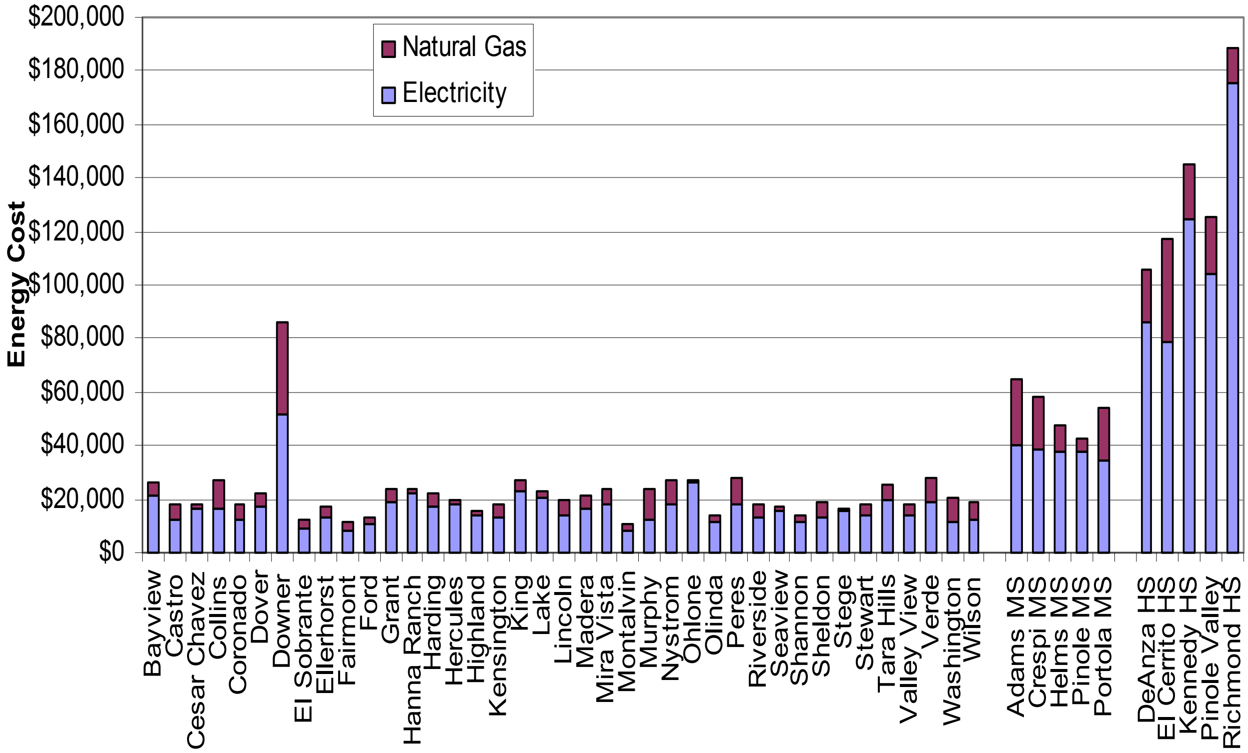

Figure *7 WCCUSD Schools Absolute Energy Consumption Cost.*

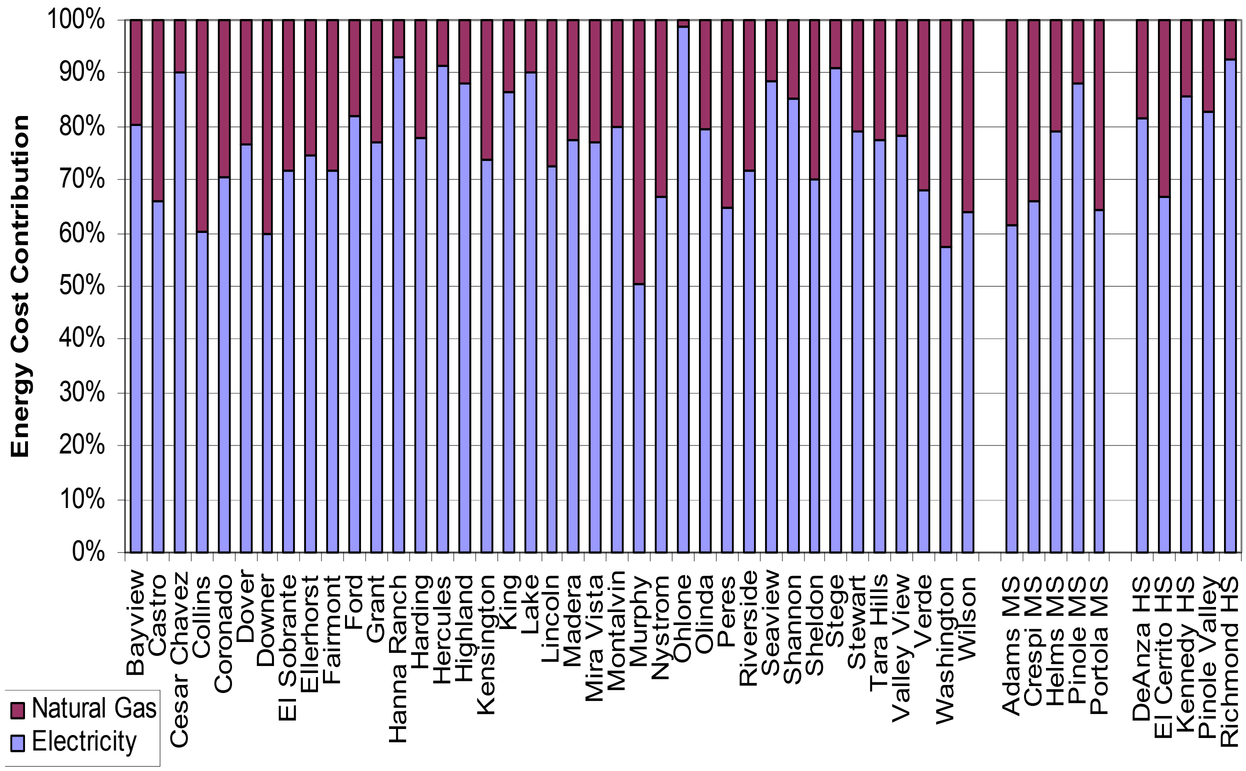

Figure 8 *Percentage Energy Cost Contribution for Electricity and Natural Gas.*

Relative Energy Consumption

Absolute energy consumption figures provide a good indicator of a building's efficiency when compared to similar buildings. However, a better indicator of the efficiency of a building is the energy consumption per unit of reference. Similarly, a better indicator of the cost-effectiveness of a building is the energy cost per unit of reference. In our particular case, the units of reference used are units of area (ft^2) and student population. Appendix C shows the school energy consumption and cost per student, while Appendix D presents the school energy consumption and cost per unit of area. These indicators permit a comparison of the performance of the schools independently of their size or student population.

The energy use per student and energy cost per student for the WCCUSD schools are presented in Figure 9 and Figure 10 respectively on the next page. Statistics for the total energy and cost per student are presented in Table 5.

High schools, on average, consume more energy per student than middle and elementary schools. Also the energy cost per student is bigger for the high schools.

Table 5 *School Energy Statistics per Student.*

	Elementary Schools		Middle Schools		High Schools		All Schools	
	kBtu/pers	$/pers	kBtu/pers	$/pers	kBtu/pers	$/pers	kBtu/pers	$/pers
Average	2682	$44.03	3470	$49.23	5106	$94.13	3010	$49.67
Median	2363	$43.64	3926	$51.83	4518	$83.27	2610	$47.26
Maximum	7753	$90.12	4492	$59.14	7398	$141.31	7753	$141.31
Minimum	1040	$22.80	2086	$37.08	3247	$57.74	1040	$22.80
St. Dev.	1282	$13.84	967	$8.48	1640	$33.65	1473	$22.00

Energy and energy cost per unit floor area statistics are presented in Table 6. Figure 11 shows graphically the energy per unit area consumed at the schools while Figure 12 presents the energy cost per unit area.

Table 6 *School Energy Statistics per Unit Area of Construction.*

	Elementary Schools		Middle Schools		High Schools		All Schools	
	kBtu/ft^2	$/ ft^2	kBtu/ ft^2	$/ ft^2	kBtu/ ft^2	$/ ft^2	kBtu/ ft^2	$/ ft^2
Average	29.6	$0.50	31.0	$0.45	40.1	$0.73	30.9	$0.52
Median	27.3	$0.48	32.4	$0.46	40.0	$0.76	28.8	$0.50
Maximum	61.3	$0.88	39.8	$0.55	49.7	$0.83	61.3	$0.88
Minimum	15.6	$0.27	23.4	$0.30	32.8	$0.59	15.6	$0.27
St. Dev.	10.1	$0.12	6.7	$0.10	6.9	$0.09	9.9	$0.14

When efficiency is measured using energy per unit area (energy intensity), we find that elementary and middle schools have approximately the same average intensity while high schools present higher energy intensity. However, the schools with the highest energy intensities are not high schools but elementary schools. Energy cost per unit area is approximately the same for elementary and middle schools but bigger for the high schools.

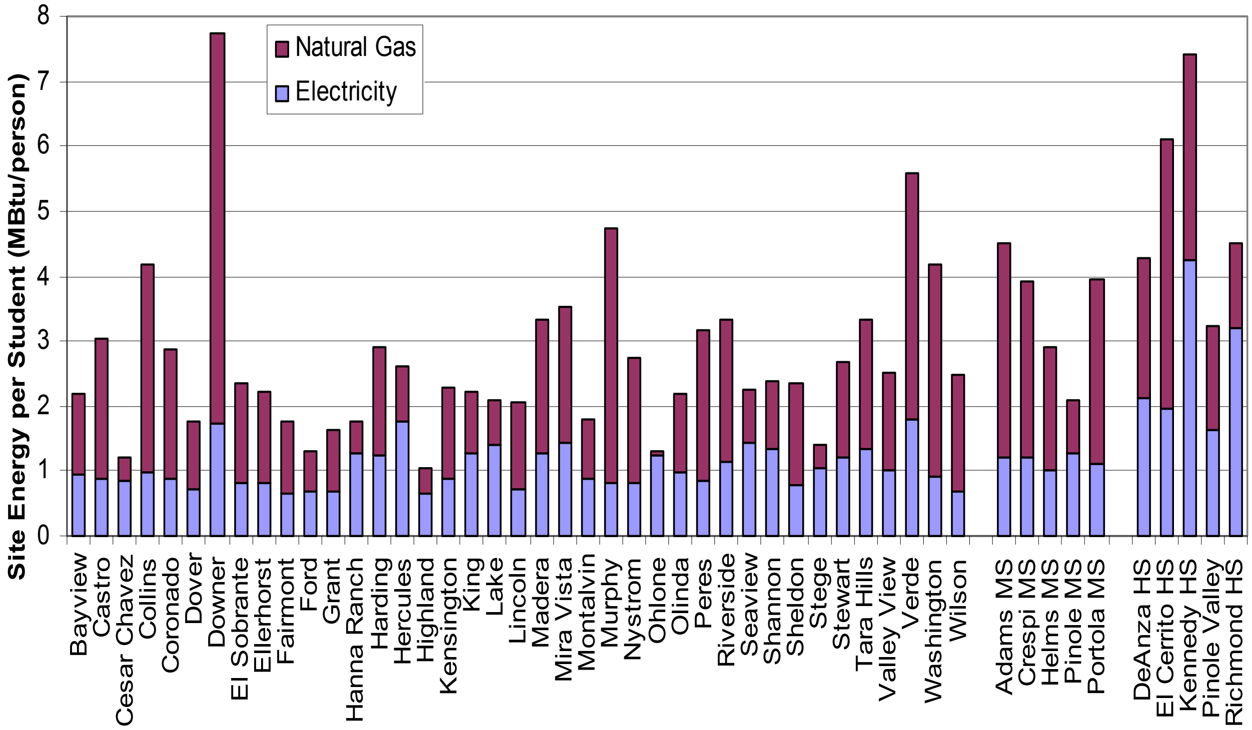

Figure 9 *WCCUSD Schools Site Energy Consumption per Student.*

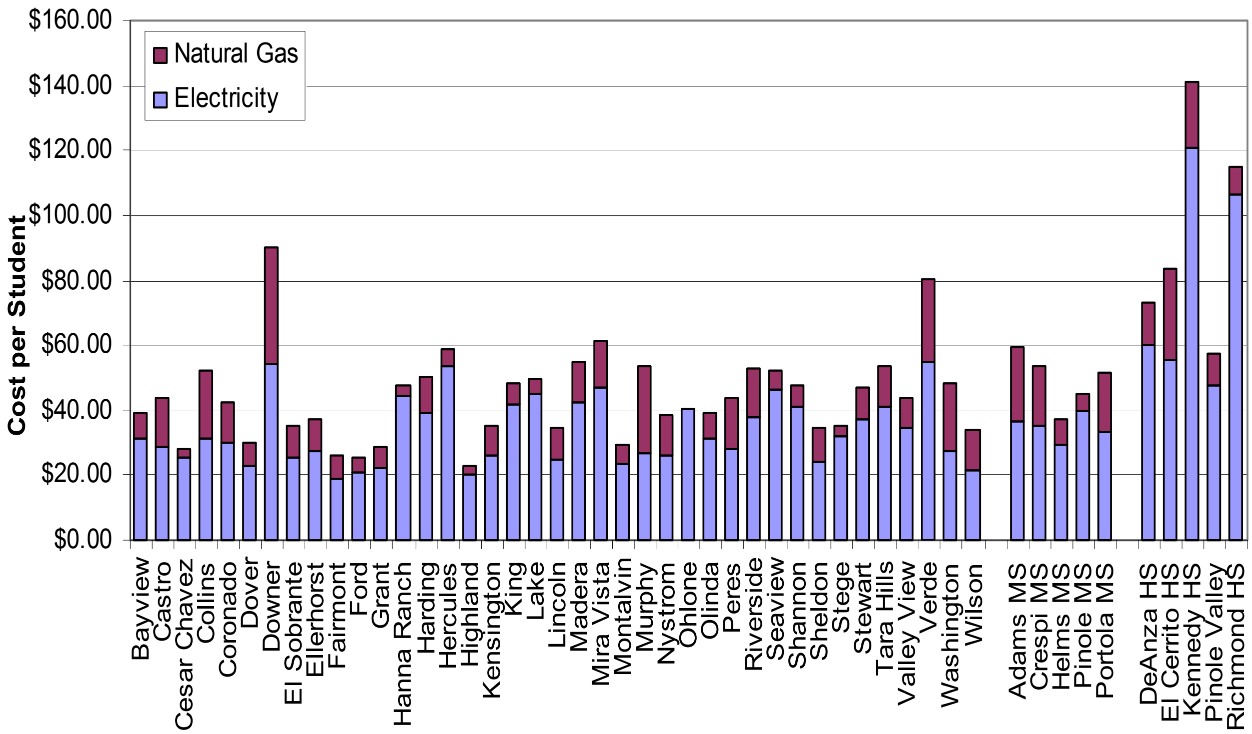

Figure 10 *WCCUSD School Energy Cost per Student.*

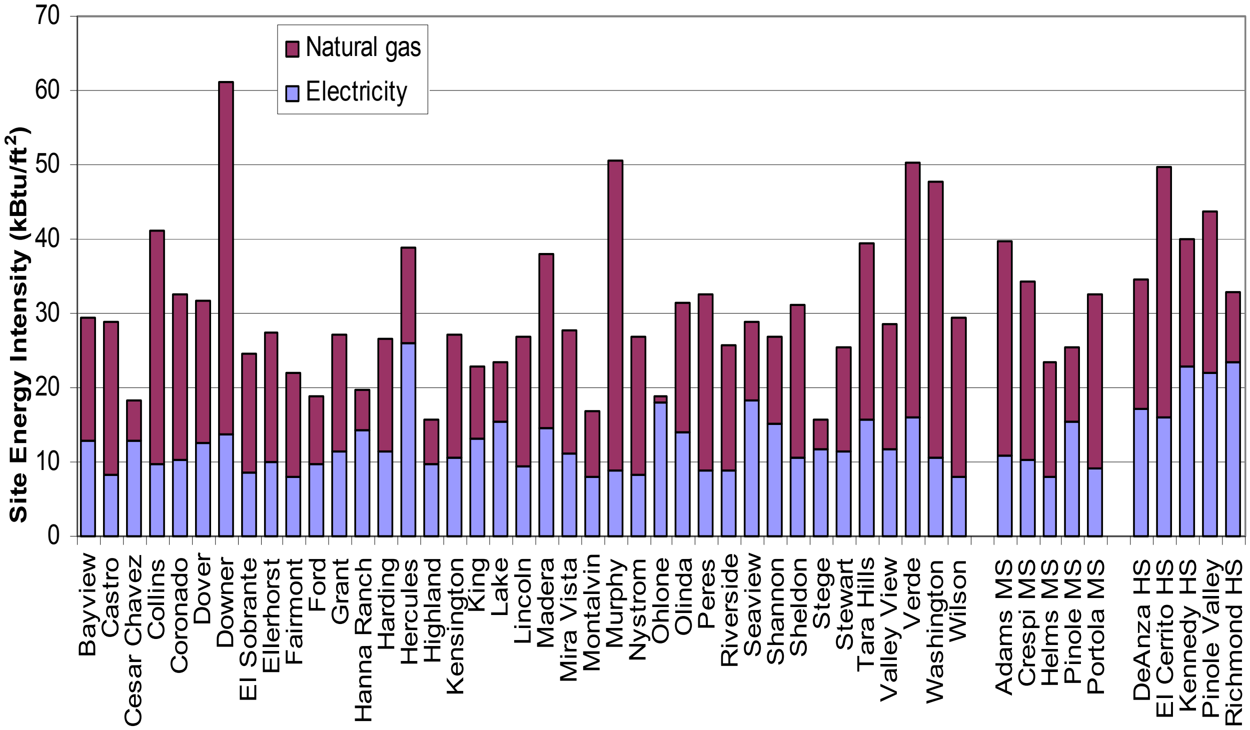

Figure 11 *WCCUSD Schools Site Energy Consumption per Unit Area.*

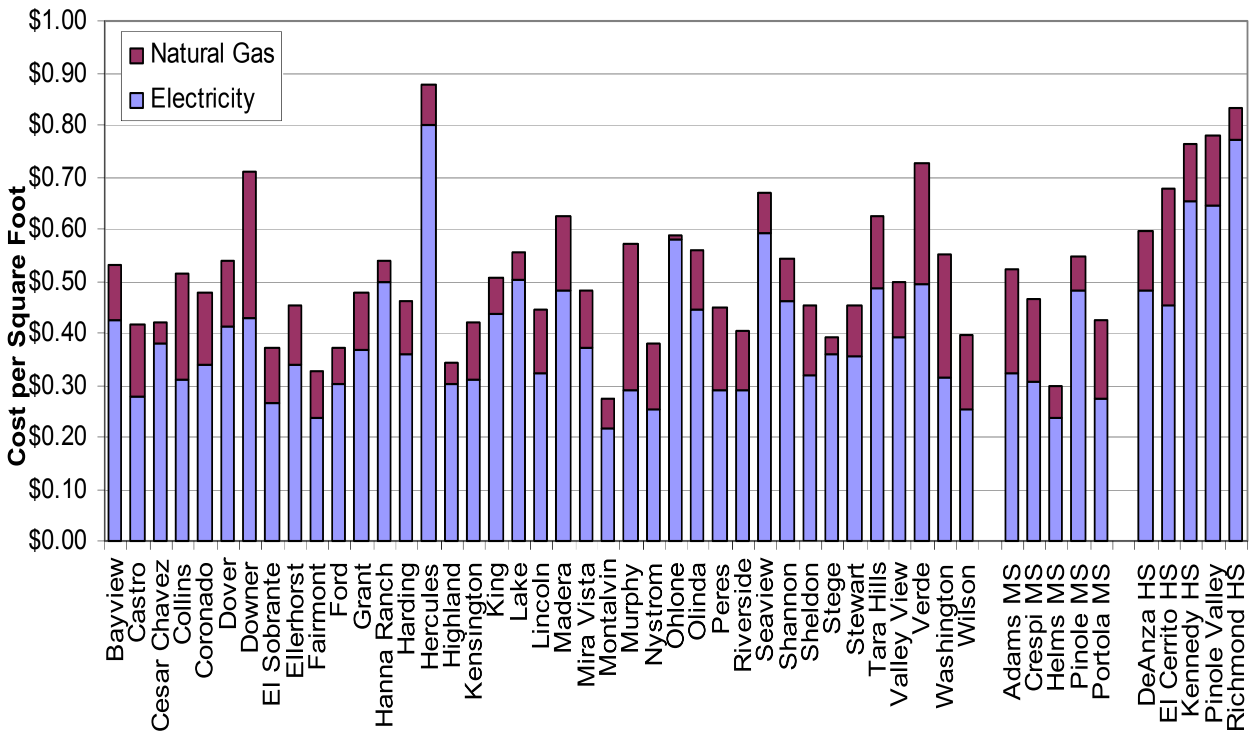

Figure 12 *WCCUSD School Energy Cost per Unit Area.*

The four relative indicators presented show, in general, that high schools as a group consume more energy than elementary and middle schools. One possible explanation might the different hours of operation of the schools. In order to consider the times of operation, the relative energy use indicators were normalized by the number of hours of class per week (Appendix E).

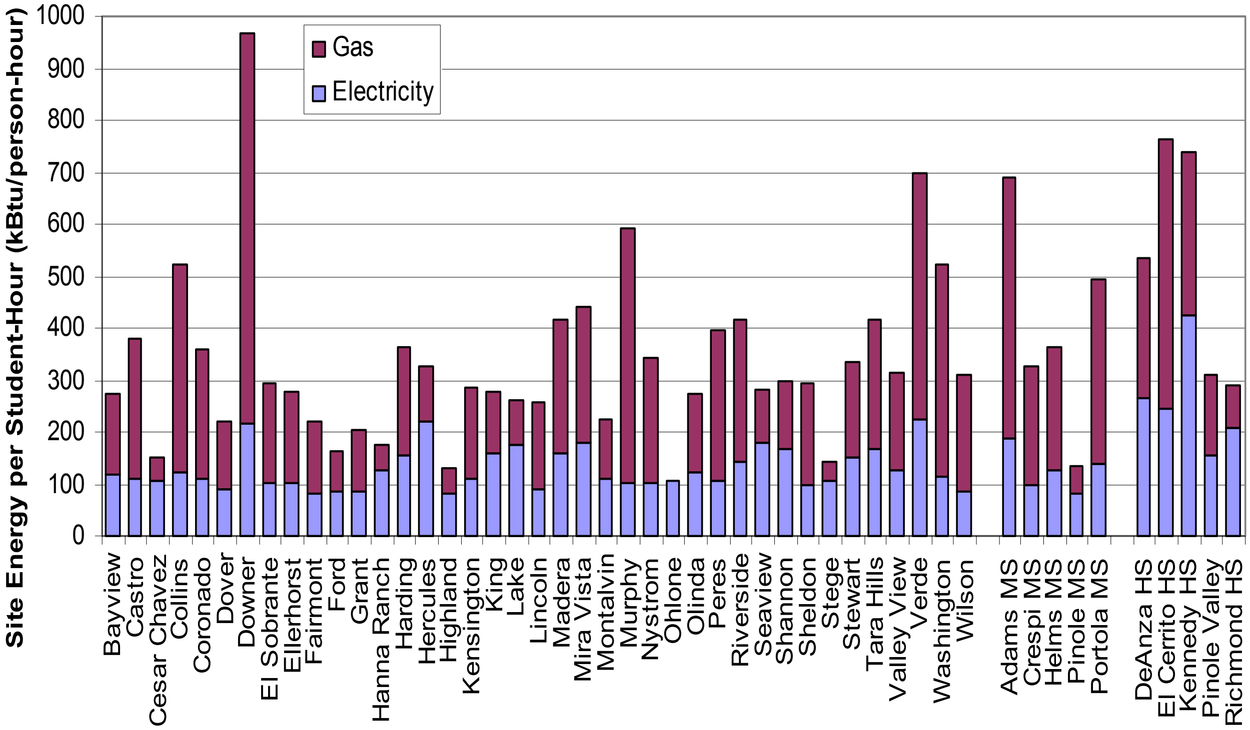

Figure 13 *WCCUSD Site Energy per Student Normalized by Hours of Operation.*

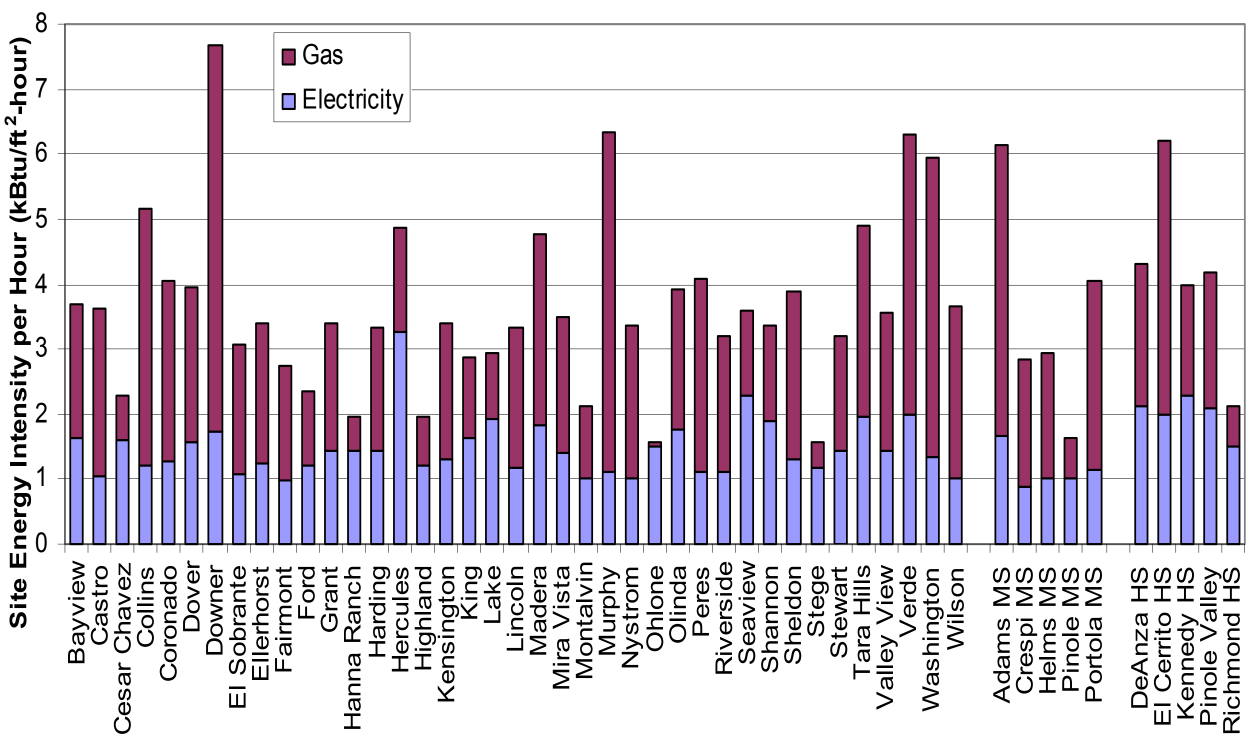

Figure 14 *WCCUSD Site Energy Intensity Normalized per Hours of Operation.*

It can be seen from the previous figures and Table 7 below, that when the relative energy consumptions are normalized by the hours of operation of the schools, the high schools still consume in average more energy than middle and elementary schools. However, some of the high schools consume less than the average of the elementary and middle schools.

***Table** 7 School Relative Energy Statistics per Hour of Operation.*

	Elementary Schools		Middle Schools		High Schools		All Schools	
kBtu per	**ft^2-hr**	**person-hr**	**ft^2-hr**	**person-hr**	**ft^2-hr**	**person-hr**	**ft^2-hr**	**person-hr**
Average	3.66	332	3.52	402	4.16	527	3.70	359
Median	3.41	295	2.92	361	4.16	533	3.48	312
Maximum	7.66	969	6.12	691	6.21	763	7.66	969
Minimum	1.56	108	1.64	135	2.12	291	1.56	108
St. Dev.	1.32	164	1.69	207	1.45	226	1.35	181

THE SCHOOL RANKING INDEX

The school energy consumption and cost were analyzed using absolute and relative indicators. The use of multiple indicators led to multiple school rankings, each one different (Appendix F). A ranking index was defined in order to present the results obtained from the different indicators using a single figure. The ranking index number was computed by taking the average of the rank positions of each school under each indicator. The indicators used were: site energy consumption and cost; site energy and cost per student; site energy intensity and cost per unit floor area; energy per student-hour of operation; and energy intensity per hour of operation. Figure 15 presents the rank index value obtained by the different schools in the district. Figure 16 shows the schools ranked based on the index.

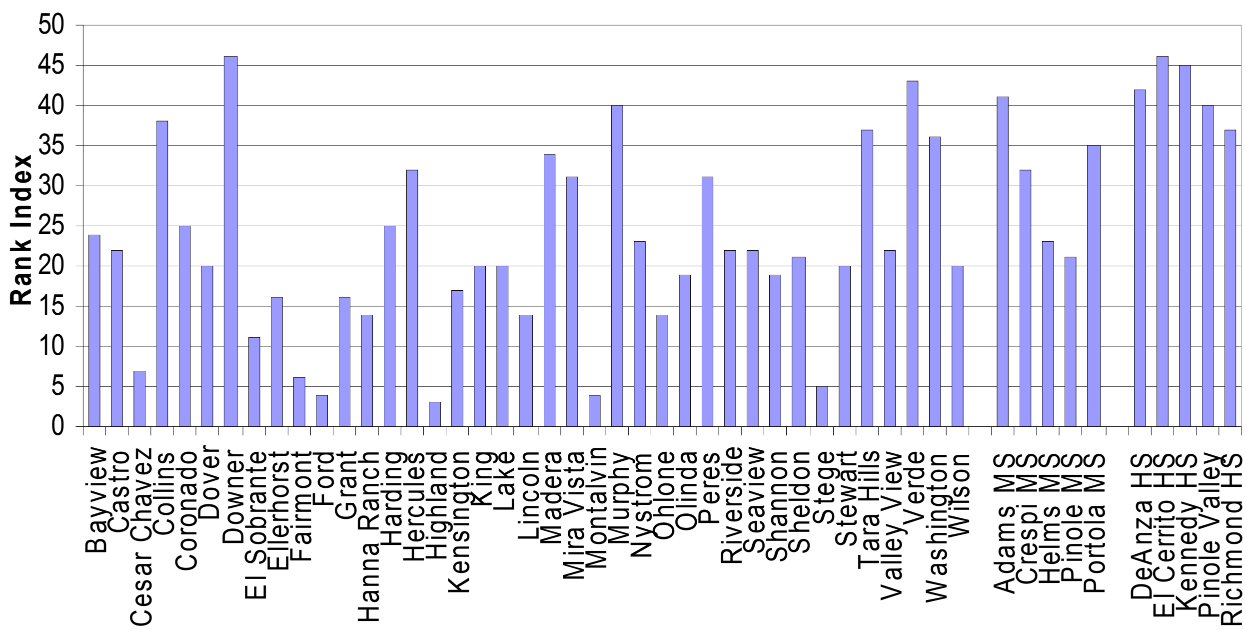

***Figure 15** Schools Rank Index Results.*

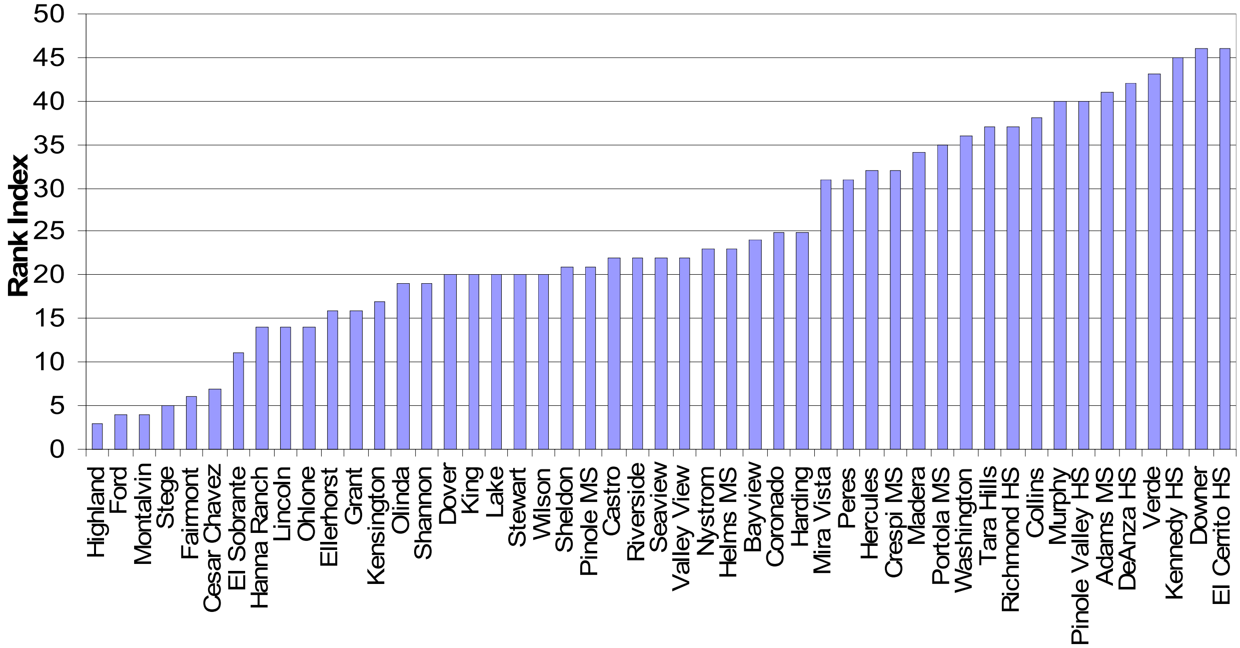

Figure 16 *School Ranking Results.*

ENERGY STAR® Benchmarking of the Schools

The EPA and the DOE have established the ENERGY STAR® criteria (http://www.energystar.gov) for commercial and K-12 school buildings to promote energy efficiency and environmental conservation. The basis for the criteria is the benchmarking of building energy consumption on a 1 to 100 scale. Buildings that earn a benchmarking score of 75 or greater are considered to be among the top 25 percent nationwide in terms of energy performance, and are eligible to apply for the ENERGY STAR label for buildings if they also conform to industry standards of indoor environment.

The ENERGY STAR model is based on source consumption and building characteristics data for K-12 schools obtained from the 1995 EIA Commercial Buildings Expenditures and Consumption Survey (1995 CBECS). The score is computed based on a comparison of the actual source energy use intensity (EUI) of the building and a predicted source EUI based on the regression analysis of the CBECS data.

The ENERGY STAR program computes the actual source EUI from the site EUI based on the type of energy (gas, electric, oil, etc.) used by the building. The predicted source EUI is a function of the following input variables: building area and its natural logarithm, hours of occupation per week, months used, student population, percentage of mechanical cooling, presence of cooking facilities, and heating degree days. The user input variables to the program are building energy consumption records for the different energy sources as well as the building location and the physical and operational characteristics. The program obtains the weather information based on the building geographic location and the dates of the energy records provided.

The ENERGY STAR Scores were computed for the 49 schools. Actual annual gas and electric records, building area, student population, and cooking facilities data were used. The hours of operation (8 hours per day) and percentage of mechanical cooling (*italic values* in Appendix A, estimates by the school's maintenance staff) were assumed for most of the elementary schools, while actual values were used for the middle and high schools.

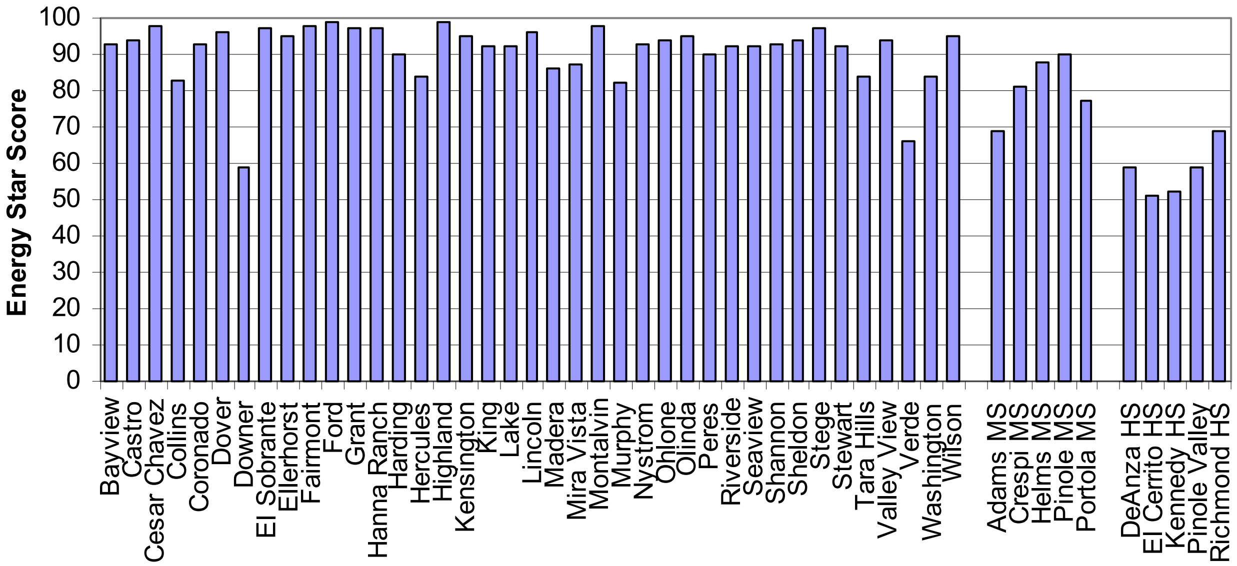

Figure 17 *WCCUSD ENERGY STAR® Scores*

Scores for the schools varied greatly, mainly based on the school type. Figure 17 presents the scores obtained using the school data. None of the high schools obtained a score above 75, while only one of the middle schools and two of the high schools did not score above 75. Table 8 presents the school score statistics. As seen in the graph and the table, the high schools scored the worst, the elementary schools scored the best, and the middle schools scored in between.

Table 8 *Energy Star Scores Statistics*

	Elementary	Middle	High	All
Average	91.2	81.0	58.0	86.7
Median	93.0	81.0	59.0	92.0
Maximum	99.0	90.0	99.0	99.0
Minimum	59.0	69.0	51.0	51.0
Std. Deviation	8.2	8.5	7.2	13.0

The figures below present the comparison between the ENERGY STAR Score and the efficiency indicators used to categorize the schools' energy performance. It can be observed that in general the ENERGY STAR Score decreases as the EUI and the energy use per student increase. A similar relation is observed between the scores and the energy cost, albeit less pronounced since energy cost is related to the energy consumption and the ratio between the different energy sources, and also because the price per energy unit varies from one location to another.

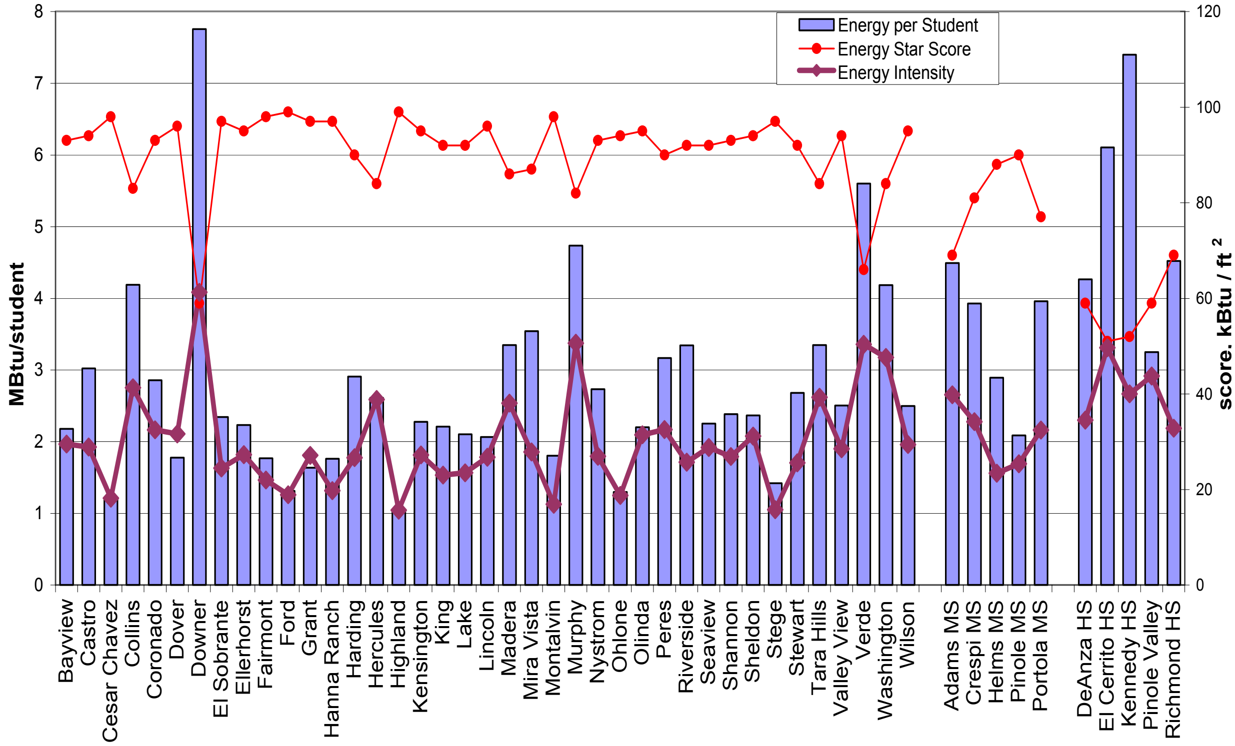

Figure 18 *WCCUSD School Energy Densities and Star Score Comparison*

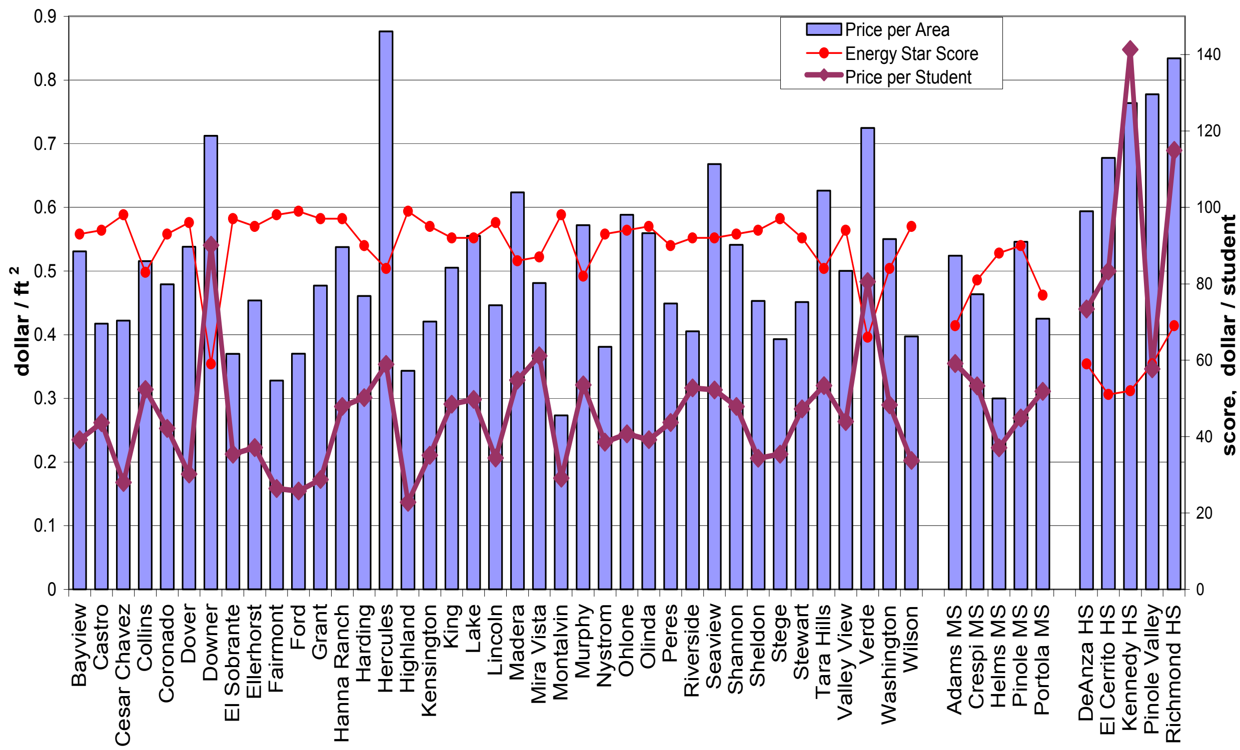

Figure 19 *WCCUSD Schools Energy Cost Densities and Star Score Comparison*

School Energy Benchmarking Results and Discussion

The energy consumption data for 49 schools (39 elementary, 5 middle, and 5 high schools) of the West Contra Costa Unified School District were analyzed in order to benchmark their performance. Two sources of energy, electricity and natural gas, are used primarily at the WCCUSD, and their cost and consumption values were compared in absolute and relative terms. Relative figures, consumption or cost per unit of reference, were found to be better indicators of the schools' performances. Finally, a ranking index was defined based on the results obtained from the absolute and relative indicator comparisons in order to rank the schools energy use performance using a single figure. Schools' energetic performances were also benchmarked using the building energy benchmarking tool ENERGY STAR® developed by the EPA and DOE. The results of the energy consumption analysis are summarized in the following paragraphs.

- In terms of energy per student used, the worst school was *Downer Elementary* followed by *Kennedy High* and *El Cerrito High*. The best schools were *Highland Elementary*, *Cesar Chavez* and *Ohlone* Elementary schools.
- The least cost-effective schools in term of dollars per student spend in energy were *Kennedy High*, *Richmond High* and *Downer Elementary*. The most cost effective are *Highland*, *Ford* and *Fairmont* Elementary schools.
- Considering the schools' energy intensity, the worst performing schools were *Downer*, *Murphy* and *Verde* elementary schools. The best performing schools were *Highland*, *Stege* and *Montalvin* elementary schools.
- From the cost per unit area point of view, the least cost-effective schools were *Hercules Elementary, Richmond High* and *Pinole Valley High*. *Downer Elementary* would be the sixth worst performer. The most cost-effective schools were *Montalvin, Helms* and *Fairmont* elementary schools.
- From the ENERGY STAR® results, the worst scores were those of the high schools and the *Downer Elementary* school.
- The worst performing schools, based on the ranking index, are *De Anza High, Verde Elementary, Kennedy High, El Cerrito High,* and *Downer Elementary* School*s*. The best performing schools are *Highland, Ford, Montalvin, Stege, and Fairmont* Elementary Schools.

The benchmarking analysis performed on the energy consumption of the WCCUSD schools identified the worst and best energy users, therefore identifying schools that would benefit the most from implementing energy conservation measures. However, this analysis was based only on the annual consumption figures and did not take into account the weather effects on the schools energy consumption. Due to the different microclimates existent in the western part of the Contra Costa County, not all the schools in the district are subject to the same environmental conditions. A better benchmarking of the schools energy consumption will be achieved once the energy data are normalized with weather data from the various microclimates in the district.

School Power and Energy Monitoring

Annual energy consumption records can be used to as general indicators of the energy efficiency of a building. However, these records do not present the daily energy consumption patterns in a building, which provide a better insight on the building energy utilization. Daily consumption patterns present when energy is used in a building, and could be used to develop changes in the energy consumption that could result in lower energy utilization or reduced energy costs by shifting the times of consumption.

Non-Intrusive Load Monitoring machines (NILM) were installed at two schools in the WCCUSD: Hanna Ranch Elementary School and Pinole Middle School. The NILM machines record electrical power consumption at the supply point of an electrical distribution panel. Two NILM machines were installed at each school, one monitoring whole school electricity consumption, and the other monitoring the electricity consumption at a secondary electrical distribution panel serving a group of classrooms from the schools. The NILM machines are accessed remotely via the Internet. Commercially available power metering and logging systems were also installed at the schools to provide parallel sub-metering of the monitored distribution panels in order to validate the observations made using the NILM machines.

The parallel power metering system used in the schools is a Highland Technology® sixteen-channel power meter and logger model K20. The K20 logger collects and stores one-minute averages of the power measured on each of the sixteen channels. The K20 data are retrieved using a serial connection to the NILM computer.

Daily power and energy consumption at the schools is being measured using NILM machines instead of conventional metering equipment because of their applications besides metering. For example, a NILM machine is capable of identifying individual loads, or appliances, on the monitored circuit without additional monitoring equipment, providing not only information on the time of use of energy, but also identifying the loads consuming it. Data from the NILM can be used to track the energy consumption of individual loads, and to detect and diagnose equipment faults.

Hanna Ranch Elementary School

The Hanna Ranch Elementary School is composed of five similar buildings housing classrooms and two larger buildings housing the staff and support offices, the library, the computer lab, a cafeteria, a performing arts facility, and a multi-purpose room. Each of the small buildings houses 4 classrooms and an interior small group teacher's room, with the exception of building E, which houses 3 classrooms, the electrical room, a storage room and student restrooms. Figure 20 shows a schematic plan of the school site.

The main panel NILM monitors the power consumed by the seven school buildings, while the secondary panel NILM monitors the power consumed only by building E. The K20 sub-metering system described previously was also installed at the secondary distribution panel.

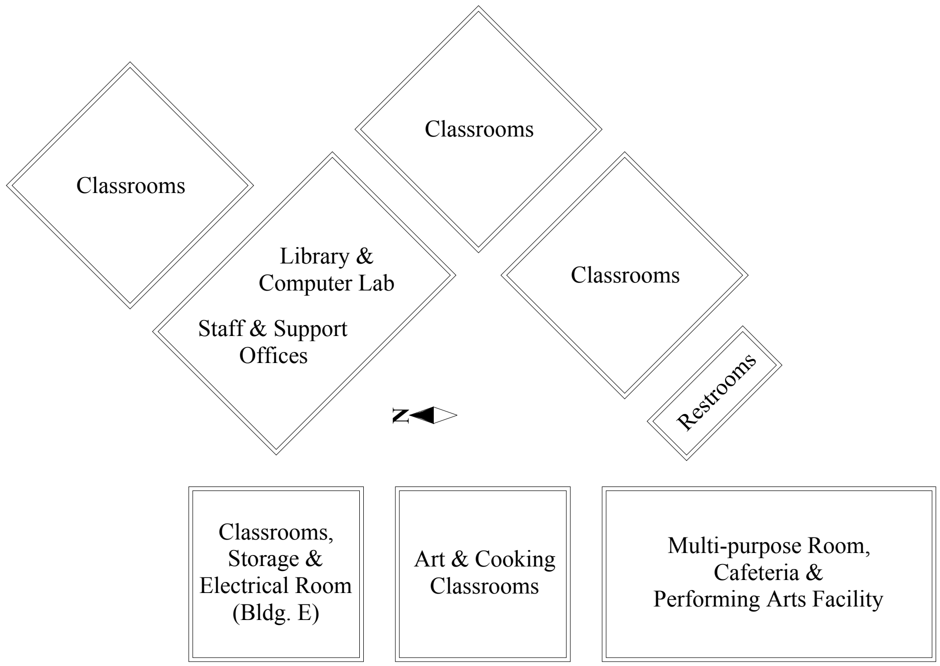

Figure 20 *Hanna Ranch School Schematic Plan.*

Main Distribution Panel

The following figures present samples of the power consumption recorded at the main electrical distribution panel of the school during the heating season. Each figure shows seven continuous days of power consumption. The first two figures (Figure 21 and Figure 22) show the power consumption during normal school weeks, while the third one (Figure 23) shows the power consumption during a school holiday week. Figure 24 shows samples of the three different diurnal cycles observed on the weekly plots. The following observations are made based on the mentioned figures.

- During school days, power consumption increases from the nighttime steady-state value at around 7:00am reaching a plateau at 9:00. Power decreases around noon to increase again in the afternoon and decrease around 3:30pm to an evening plateau at a higher value than the nighttime steady-state value. The evening plateau ends abruptly around 11:00pm reducing the power consumption to the nighttime steady-state value.
- Weekend power consumption stays constant during the day at the nighttime steady-state value. At around 4:30pm a step increase in power consumption is registered (the evening plateau) which ends around 11:00pm to bring the power back to the nighttime steady-state value.
- Weekday power consumption during school holidays presents the same power consumption pulse observed from 4:30pm to 11pm during the weekend consumption. However, daytime consumption shows an increase in power use at 7am that ends at 3:00pm, although much smaller in magnitude than the increase presented during a normal school day. The smaller consumption is due to the fact that during the holiday only the administrative and maintenance staffs were present at the school.

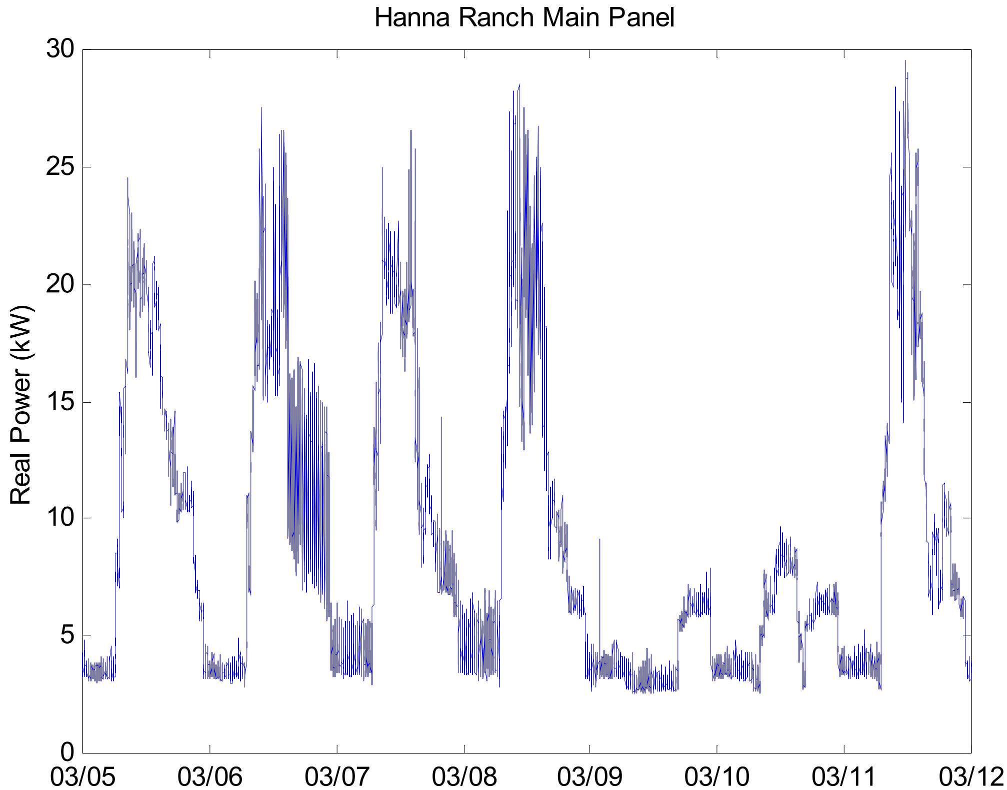

Figure 21 *Hanna Ranch Main Electrical Panel – Normal Week in March.*

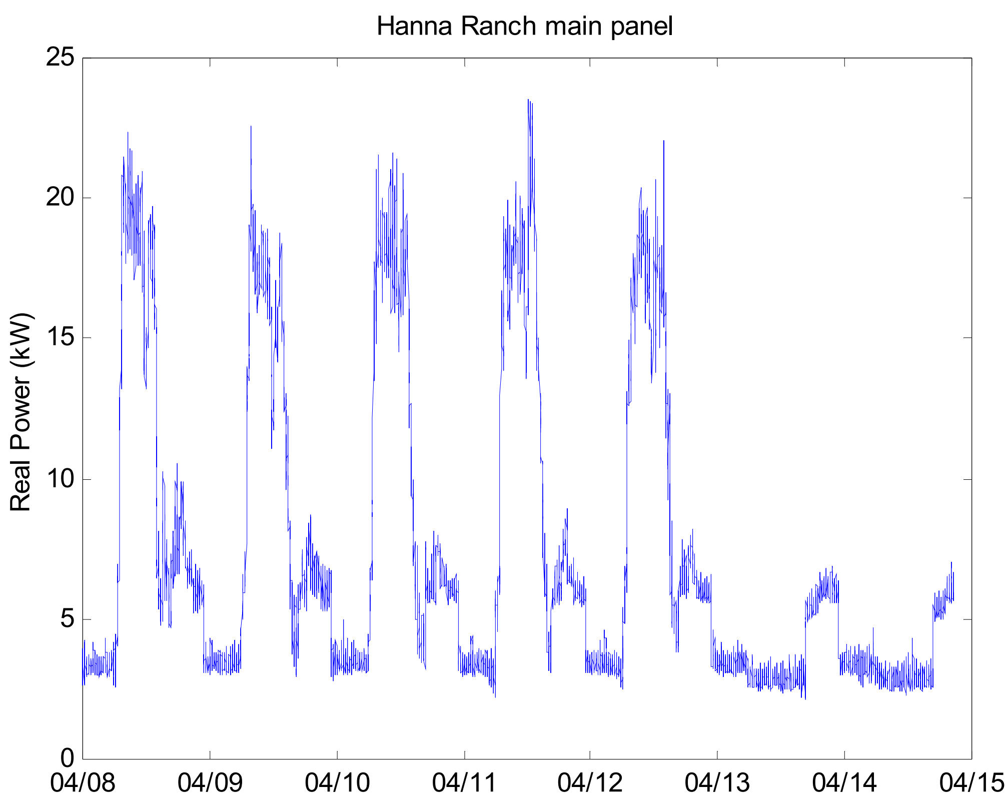

Figure 22 *Hanna Ranch Main Electrical Panel – Normal Week in April*

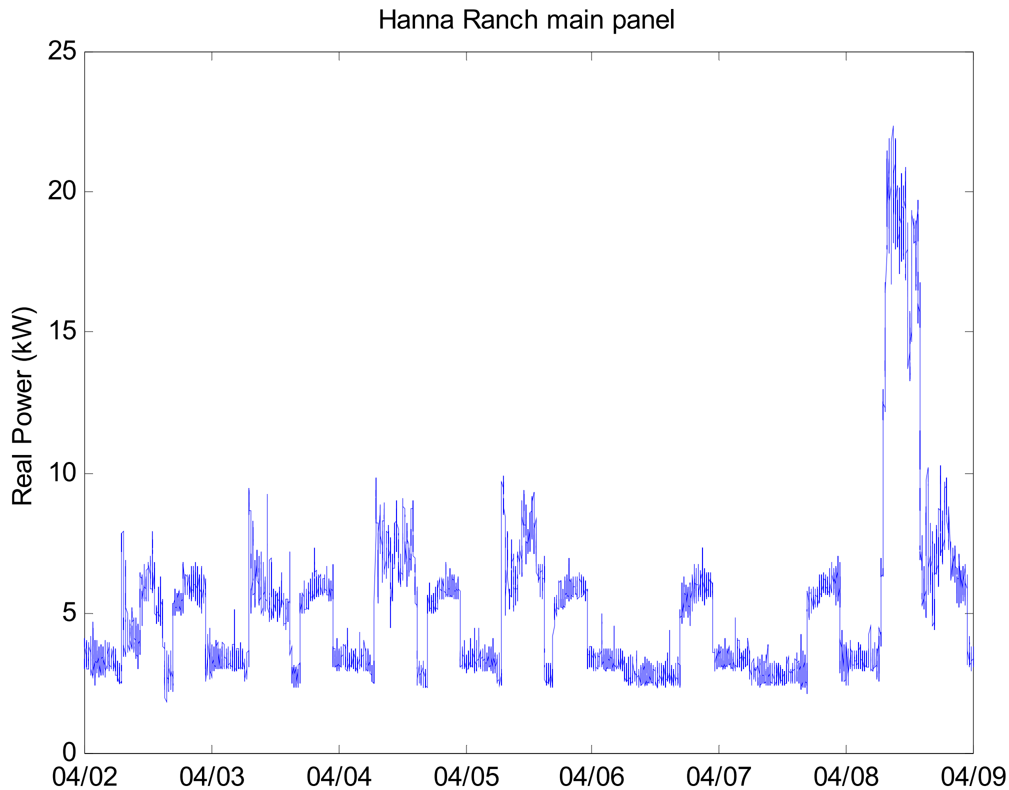

Figure 23 *Hanna Ranch Main Electrical Panel – Holiday Week.*

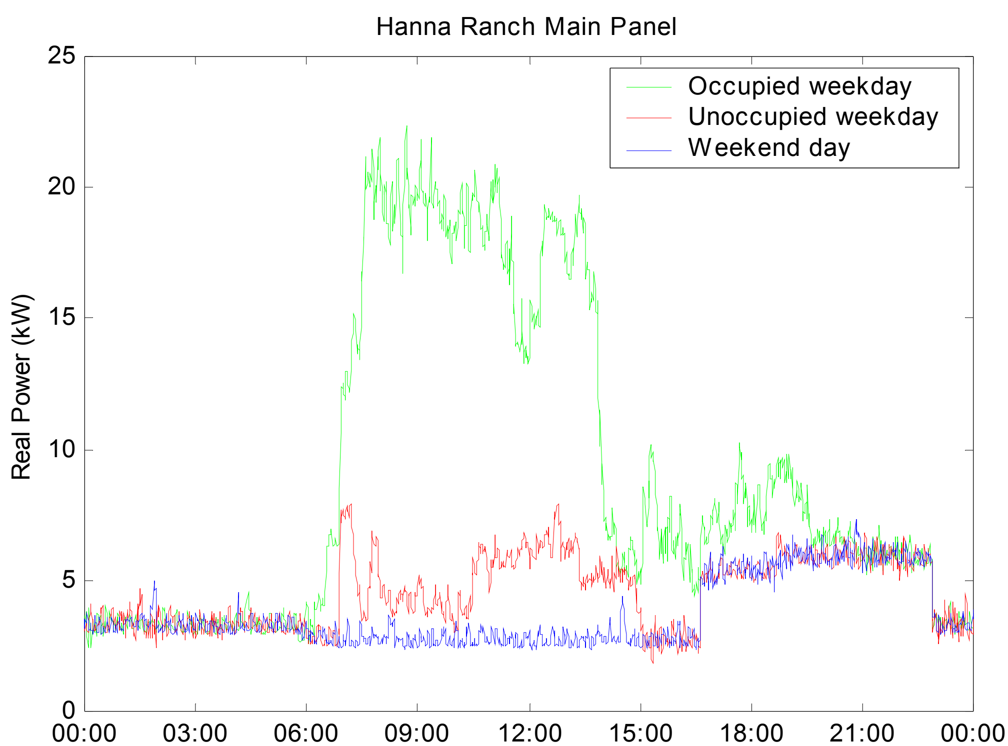

Figure 24 *The Different Daily Consumption Patterns at Hanna Ranch Main Panel.*

It is interesting to note in Figure 21 that some electrical activity was recorded during the afternoon of March 6 that was not observed during the other days presented. Figure 25 shows the power waveform recorded during March 6, and a detail of the observed oscillations.

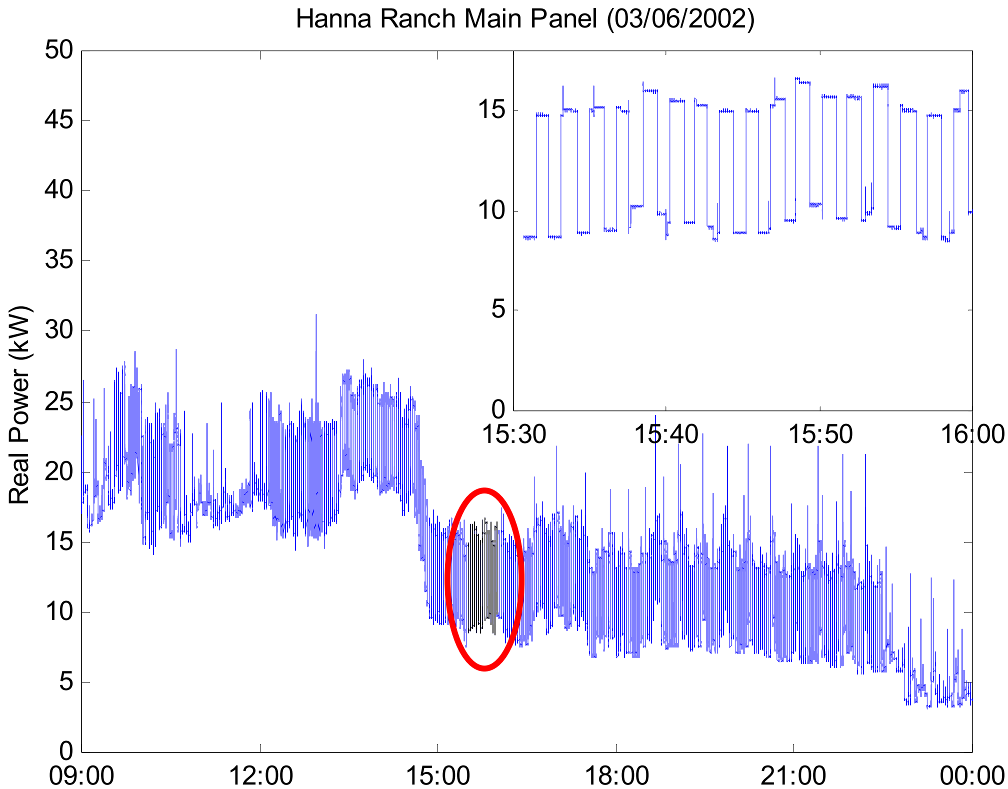

Figure 25 *Hanna Ranch Main Panel Consumption Detail on March 6, 2002.*

The shape and frequency of the oscillations observed suggests, based on previous experience, the operation of device containing a heating element controlled by a thermostat, such as an electric kiln or an electric water heater.

Secondary Distribution Panel

As mentioned previously, the secondary electrical distribution panel being monitored at Hanna Ranch services a single building (building E) containing three classrooms, a small group room, a storage room, an electrical room, and student restrooms. Figure 26 presents a schematic plan view of building E showing the room distribution and orientation.

The HVAC (Heating, Ventilation and Air Conditioning) equipment in each classroom consists of a split air conditioning unit with gas fired heating, and an exhaust fan.

The evaporator/heater module of the air conditioning unit is installed inside the room, on the outside corner (opposite the small group room), while the condensing module is on the rooftop of the covered walkways. A duct with registers hanging from the ceiling is used for supply air. The classroom exhaust fan is located in the plenum space above the small group room. Exhaust air is removed from the room through registers on the wall and ducted to the outside. Fresh air intakes are located on each side of the outside corner of the room next to the windows, while exhaust air-louvers are located at the other end of the exterior walls. Return air to the evaporator-heater module is through grills next to the access door.

Figure 27 shows the layout of the HVAC equipment in the classroom as well as the air movement patterns. Pictures of the HVAC equipment are presented in Figure 28.

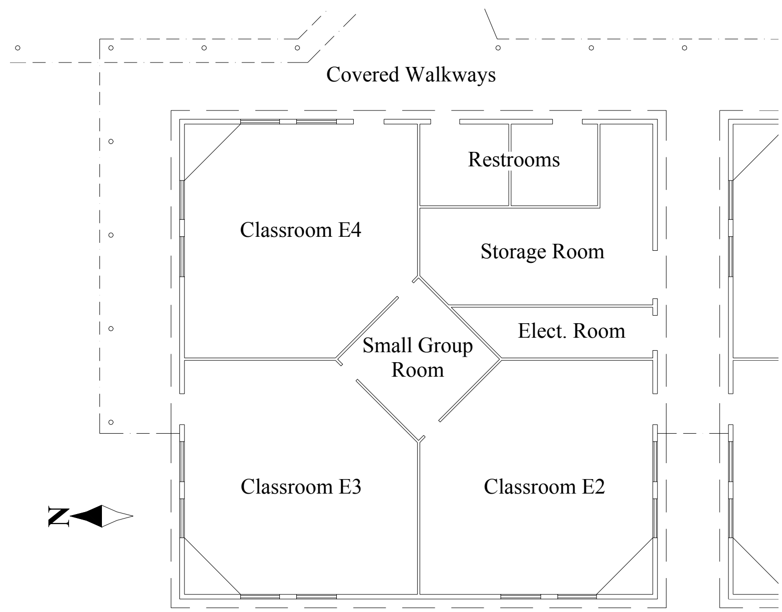

Figure 26 *Building E Schematic Plan and Classroom HVAC*

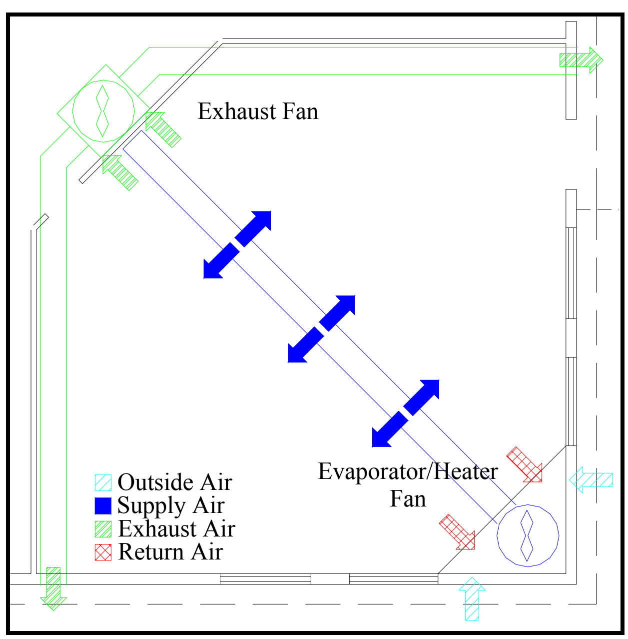

Figure 27 *Hanna Ranch Classroom HVAC Equipment Layout.*

Blue Supply Duct, Wall Exhaust Registers.

Green Exhuast Duct

Return Grill and Evaporator/Heater Access Door

Fresh Air Intake (Left), Exhaust Louver (Right), Roftop Condensing Unit

Figure 28 *Hanna Ranch Classroom HVAC Equipment Pictures.*

An energy management system (EMS) is used at Hanna Ranch to control the operation of the mechanical equipment in the classrooms and offices. Table 9 presents the general settings of the EMS. Building users can override the EMS settings locally for a short period of time.

Table 9 *Energy Management System General Settings*

Name	Value
Occupied Start Time	7:30am
Occupied End Time	3:30pm
Cooling Set Point	74°F
Economizer Set Point	72°F
Heating Set Point	68°F
Dead Band	1.75°F

Lights in the classrooms are controlled manually, while a timer controls the night-lights outside the buildings. The timer turns on the lights at 4:30pm (7:30 during the summer) and turns them off at 11:00pm. Exhaust fans provide ventilation for the restrooms, the storage and electrical rooms. These exhaust fans are on non-switched circuits and they run continuously unless their breakers are turned off.

The loads monitored by the NILM and K20 systems are presented in Figure 29 and Table 10. The figure shows the load connections graphically, while the table describes the loads connected to each phase of the panel and the corresponding K20 channel used to monitor them. The K20 system is monitoring the loads connected to all three phases on the distribution panel. The NILM monitors only the loads on phase A.

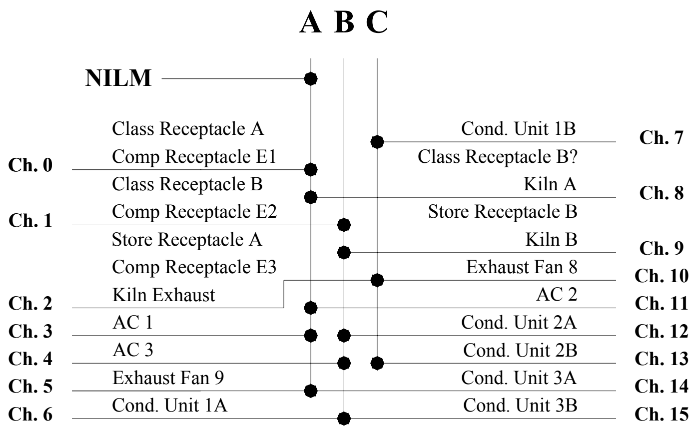

Figure 29 *Hanna Ranch NILM and K20 Sub-Panel Connections.*

Figure 30 and Figure 31 present the real power consumption recorded by the NILM on phase A of the sub-panel during two weeks. The first figure presents the power during a week in March (normal school week) when heating was used, and the second shows a week in June (summer vacation week) when the air conditioner was used.

Table 10 *K20 Monitored Loads by Circuit Phase.*

Phase	Channel No.	Load Descriptions
A	0	Classroom and Comp. Receptacles E1
	3	Split A/C Evaporator (heater) 1
	5	Exhaust Fan 9 (Electrical Room)
	8	Kiln A and Classroom Receptacles
	11	Split A/C Evaporator (heater) 2
	14	Split A/C Condensing Unit 3A
B	1	Classroom and Comp. Receptacles E2
	4	Split A/C Evaporator (heater) 3
	6	Split A/C Condensing Unit 1A
	9	Store Receptacles and Kiln B
	12	Split A/C Condensing Unit 2A
	15	Split A/C Condensing Unit 3B
C	2	Store and Comp. Receptacles E3, Kiln Fan
	7	Split A/C Condensing Unit 1B
	10	Exhaust Fan 8 (Restrooms)
	13	Split A/C Condensing Unit 2B

The figures show that there are devices on the monitored circuit that remained on continuously, and equipment on a periodic schedule (such as the night lights) turning on and off at approximately the same times every day. It can also be seen that some devices, such the HVAC equipment and classroom loads, operated during the daytime when the school was occupied (Figure 30: first five days; Figure 31: second and third days). In addition to the normal equipment, the June week waveform also shows that the kiln was used. These observations were verified using the data obtained from the parallel sub-metering system.

Figure 32 presents the K20 and NILM waveforms from March 18, 2002. Figure 33 presents the K20 and NILM waveforms from June 19, 2002. The following observations are made based on the mentioned figures:

- The exhaust fan operates continuously during both the March and June days.
- Some loads on the receptacles and kiln circuits operate on a timer, while others are active during school days.
- The A/C evaporator/heater units operated during the March day only between approximately 7:00am and 3:00pm, the times the school is occupied. The A/C condensing unit did not operate because the system was in heating mode.
- The operation of the A/C evaporator units (Unit 1 and 2) observed by the NILM during the June day did not correspond to the observed condensing unit (Unit 3) because they are in different rooms, and therefore subject to different thermal loads.
- The kiln was observed only in the June, in both the NILM and K20 power waveforms.

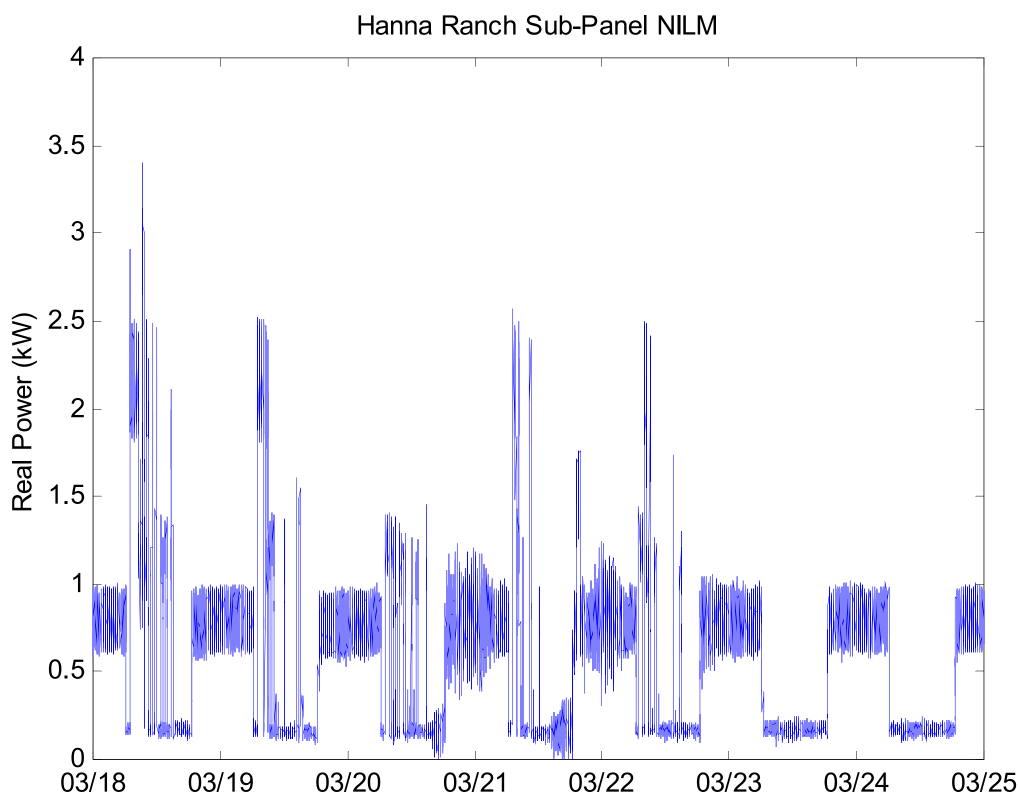

Figure 30 *Hanna Ranch Secondary Electrical Panel – Week in March.*

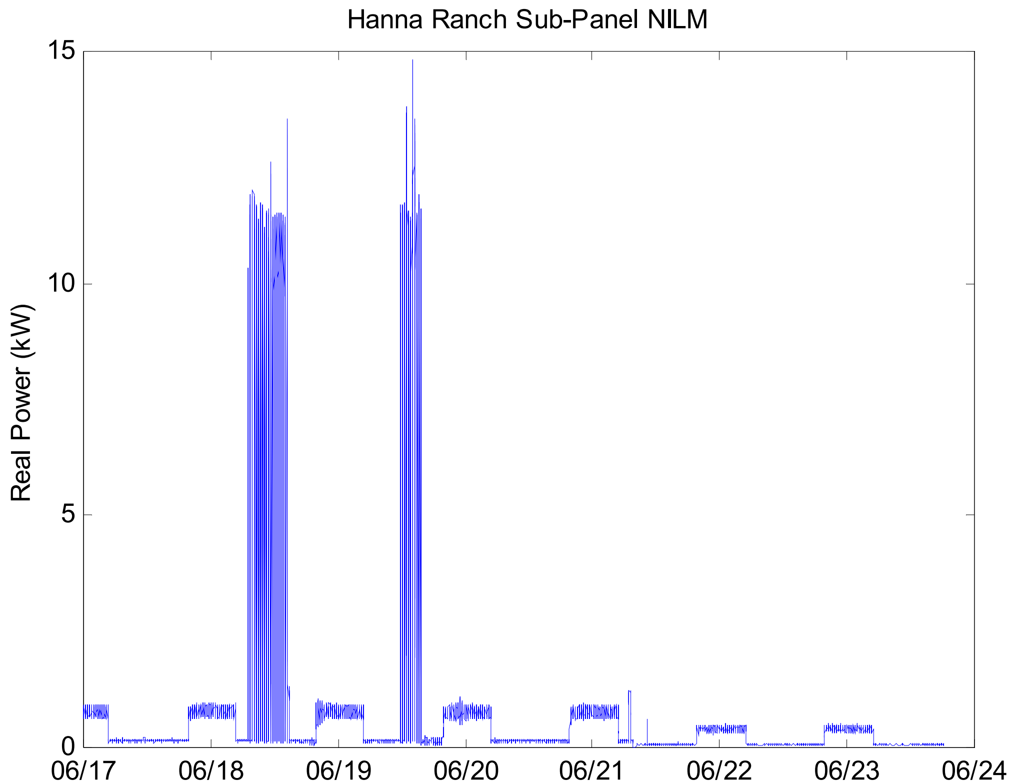

Figure 31 *Hanna Ranch Secondary Electrical Panel –Week in June.*

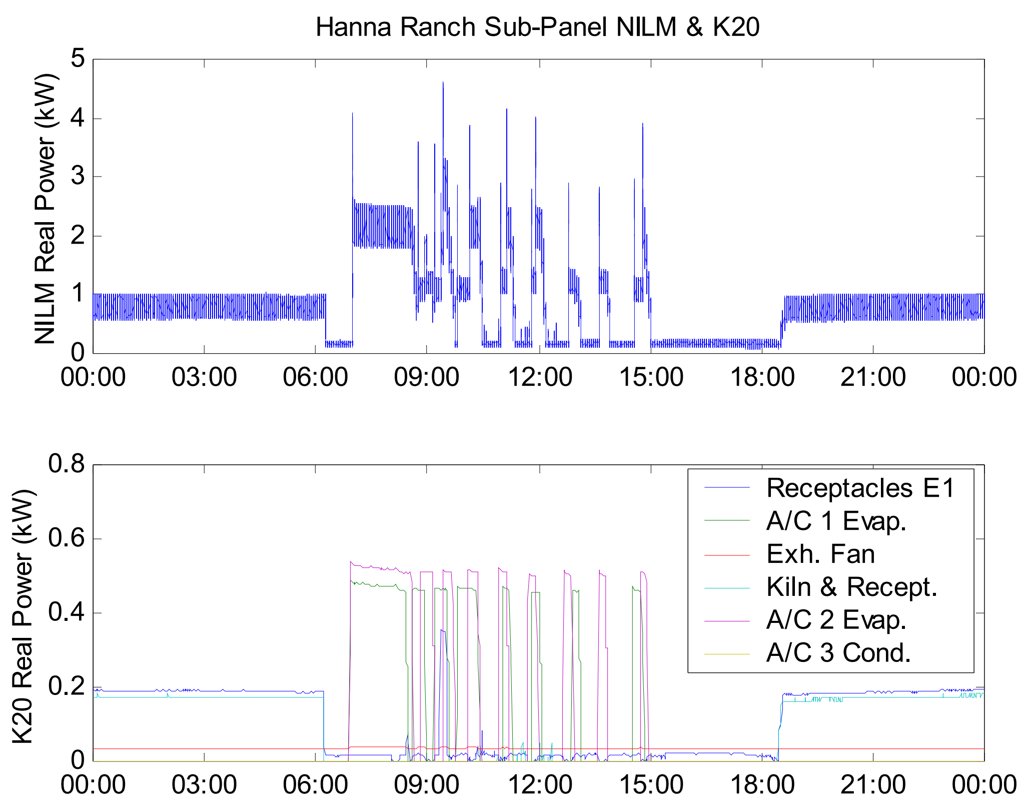

Figure 32 *Hanna Ranch Sub Panel NILM and K20 Waveforms. March 18, 2002.*

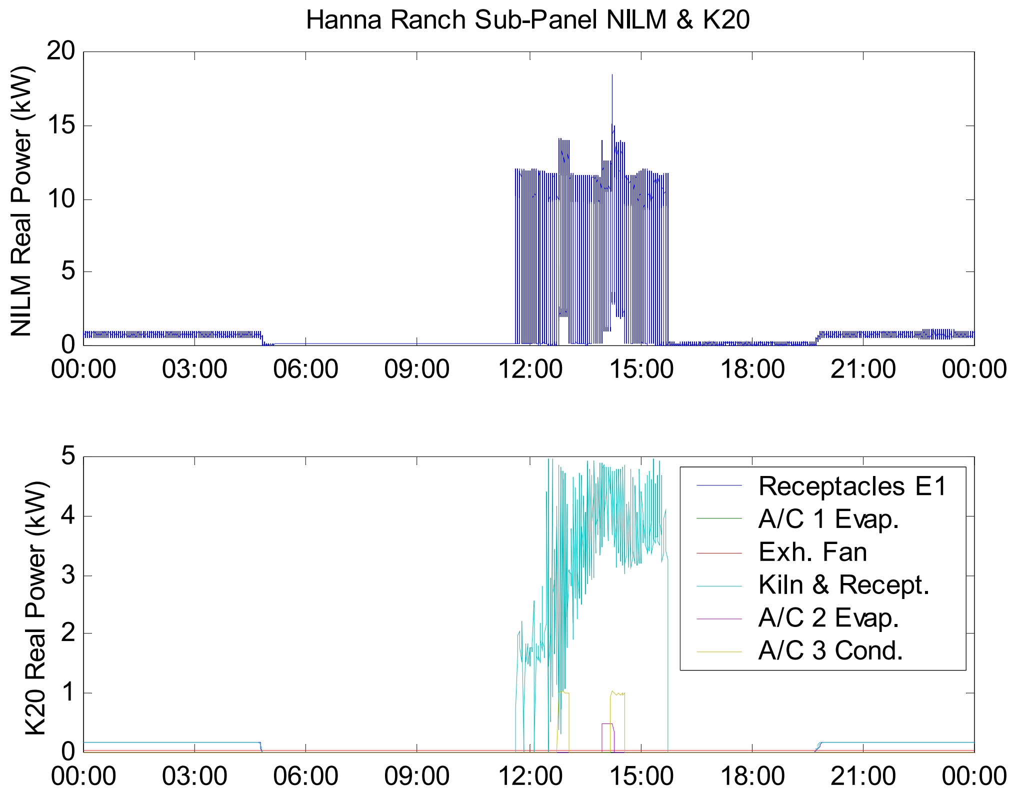

Figure 33 *Hanna Ranch Sub Panel NILM and K20 Waveforms. June 19, 2002.*

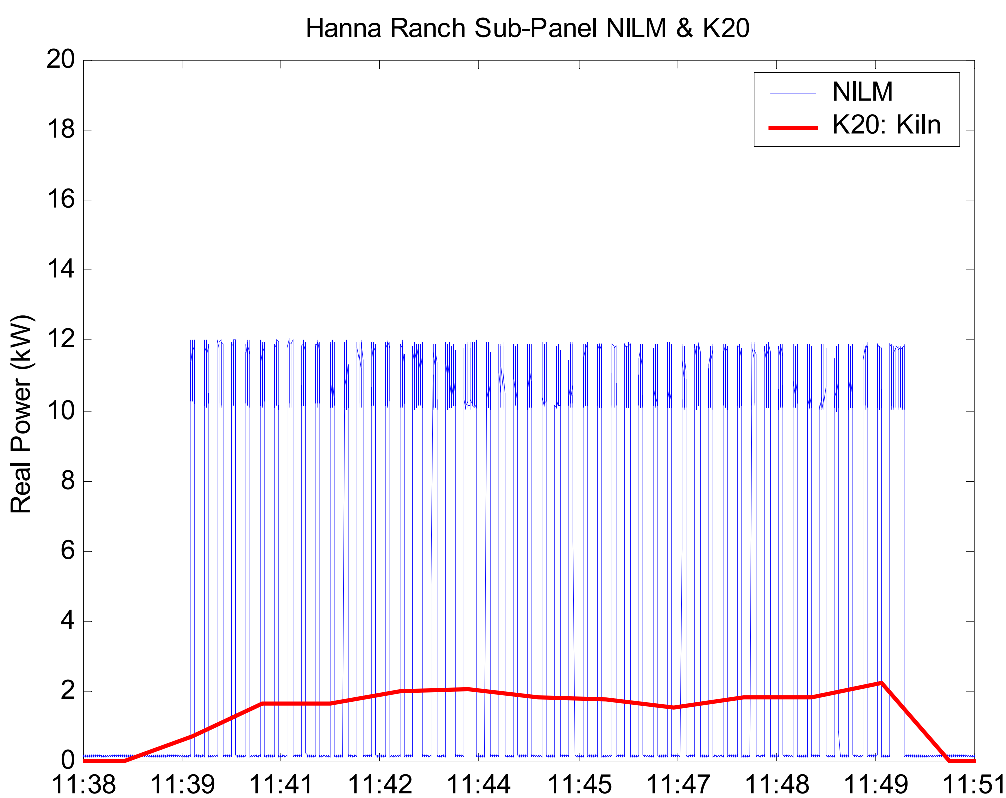

Figure 34 *Hanna Ranch Sub-Panel NILM and K20 Kiln Detail Power Waveforms.*

Figure 34 shows a comparison between the NILM power waveform and the power consumption recorded by the K20 system on the kiln channel (channel 8) during a period the kiln operated. It can be seen that kiln oscillations are observable in the NILM waveform, while they are not in the K20 waveform. The observed kiln oscillations, although normal given the nature of the device, demonstrate one of the possible applications of the NILM currently under investigation: the detection, and possibly diagnosis, of faulty appliances on the monitored circuit. The oscillations could not be revealed by conventional metering or the sub-metering system, but were detected by the NILM system. The higher sampling frequency used by the NILM (1Hz versus 1/60Hz for the K20) produces the higher resolution of the NILM waveform.

Figure 35 shows a sample of the NILM waveform in June when the air-conditioning equipment operated, together with the waveforms corresponding to K20 channels monitoring the A/C. The NILM waveform presented also shows the kiln oscillations discussed previously, along with the events corresponding to the turn-on and shutdown of the evaporating and condensing units. The ability to distinguish and classify electrical events (turn-on and shutdowns) generated by different devices in the monitored circuit is one of the main features of the NILM system. It incorporates multiple metering points into a single metering point, reducing the complexity of the monitoring hardware and its installation.

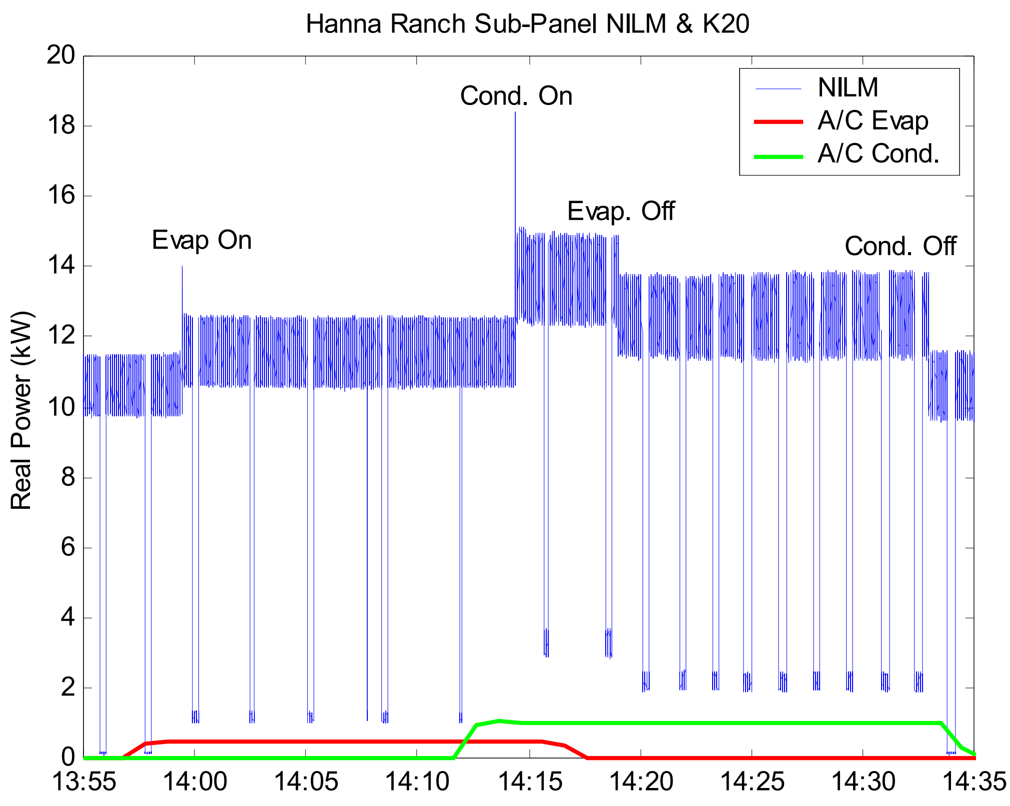

***Figure 35** NILM and K20 Waveforms Sample with A/C Components Operating.*

Pinole Middle School

The Pinole Middle School is composed of a main building (Figure 36) -housing 22 classrooms, a multipurpose room, the cafeteria and the administrative offices- and a secondary building housing the library. Furthermore there are 26 portable classroom units on the site. The main building is heated using gas fired equipment and does not have air conditioning. The portable units are air-conditioned and heated using a heat pump unit for each classroom unit.

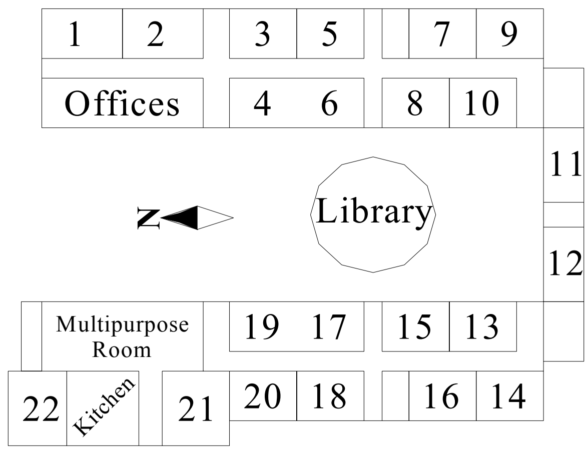

Figure 36 *Pinole Middle School Main Building Schematic Plan.*

Main Distribution Panel

The power consumption observed at the Pinole Middle School main electrical distribution panel is presented in Figure 37 through Figure 39. Again, seven continuous days are shown on each graph, with the last figure showing the power consumption during a holiday week.

The following observations about the Pinole Middle School power consumption are made based on the previous figures. Figure 40 summarizes these observations with sample power waveforms for each of the three daily consumption patterns observed.

- During school days the power consumption starts increasing from the nighttime steady state at about 6:00am reaching a peak value between 9:00 and 10:00am. Power consumption then decreases gradually and reaches the nighttime steady-state value at around 10:00pm.
- Weekend power consumption stays constant at the nighttime steady-state value, with a pulse increase in power showing up some Saturdays between 9:00am and 6:00pm.
- Weekday power consumption during school holiday presents the pulse shaped consumption that starts at around 8:00am and ends around 3:00pm. The magnitude of this pulse is slightly larger than the magnitude of the pulse present on Saturdays.

It is interesting to note that both in Hanna Ranch and Pinole, a non-zero steady state power consumption value was observed during all days. It could be attributed to loads continually on such as computer equipment, exhaust fans and kitchen equipment.

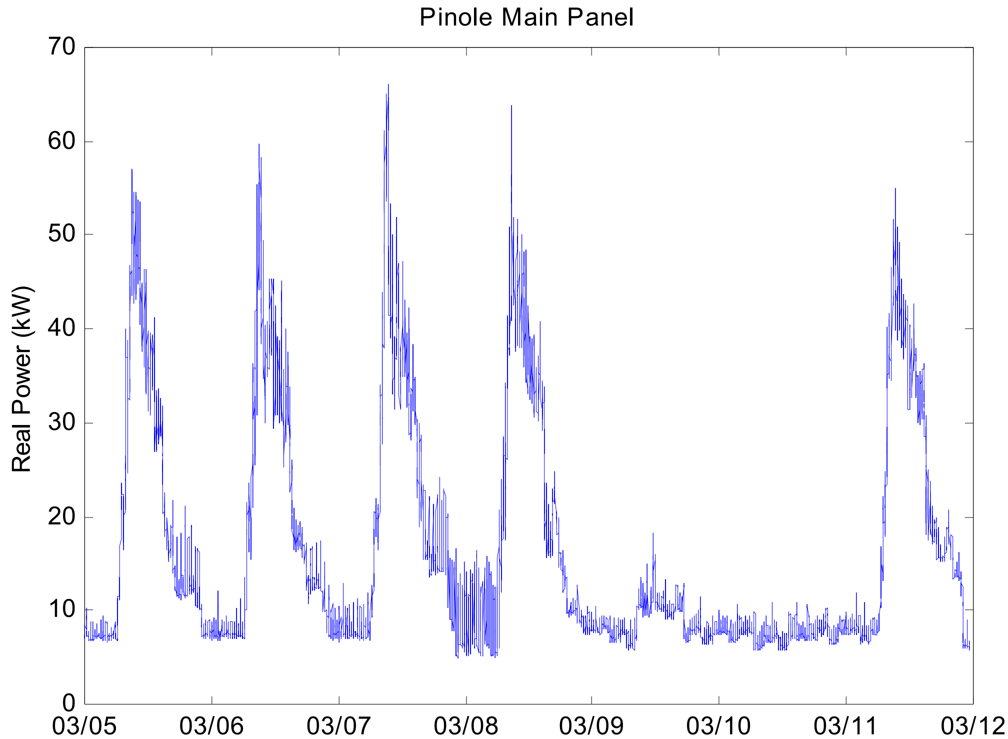

Figure 37 *Pinole Main Electrical Panel – Normal Week in March*

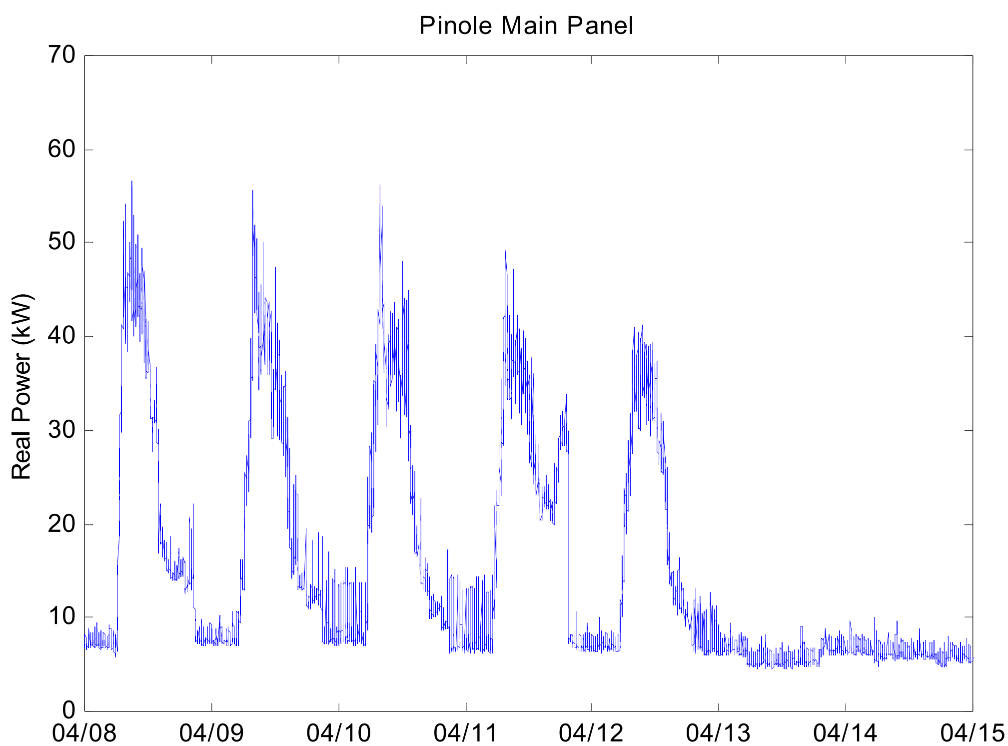

Figure 38 *Pinole Main Electrical Panel – Normal Week in April*

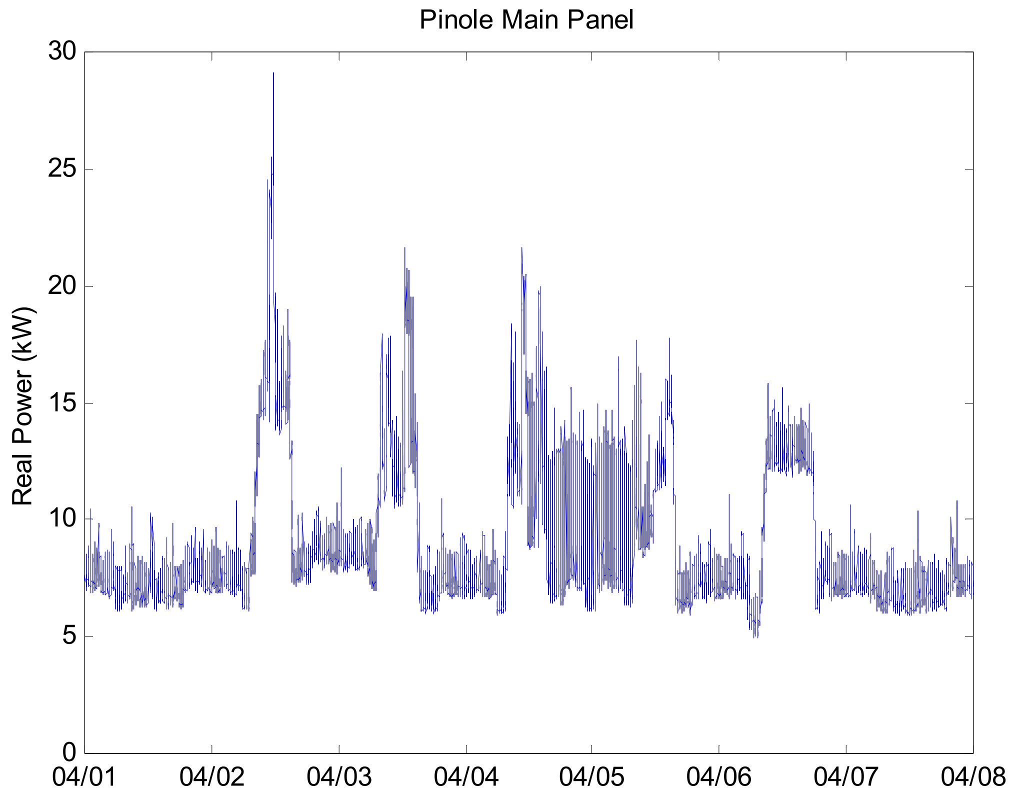

Figure 39 *Pinole Main Electrical Panel – Holiday Week*

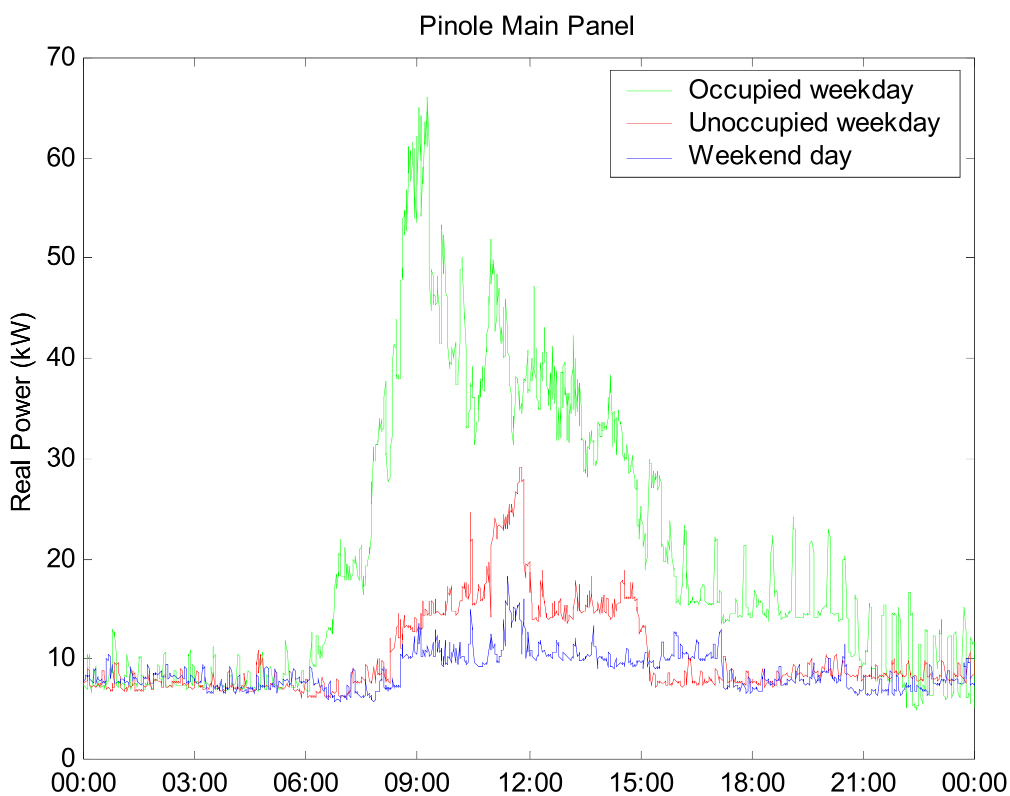

Figure 40 *Consumption Patterns for Different Day Types at Pinole Main Panel*

In addition to the consumption patterns described previously, the power waveforms of the March week (Figure 37) and the April holiday weeks (Figure 39) also show atypical power oscillations which could be indicative of potentially abnormal behavior of one or more devices. A sample of these oscillations, from the afternoon of March 4, is presented in Figure 41.

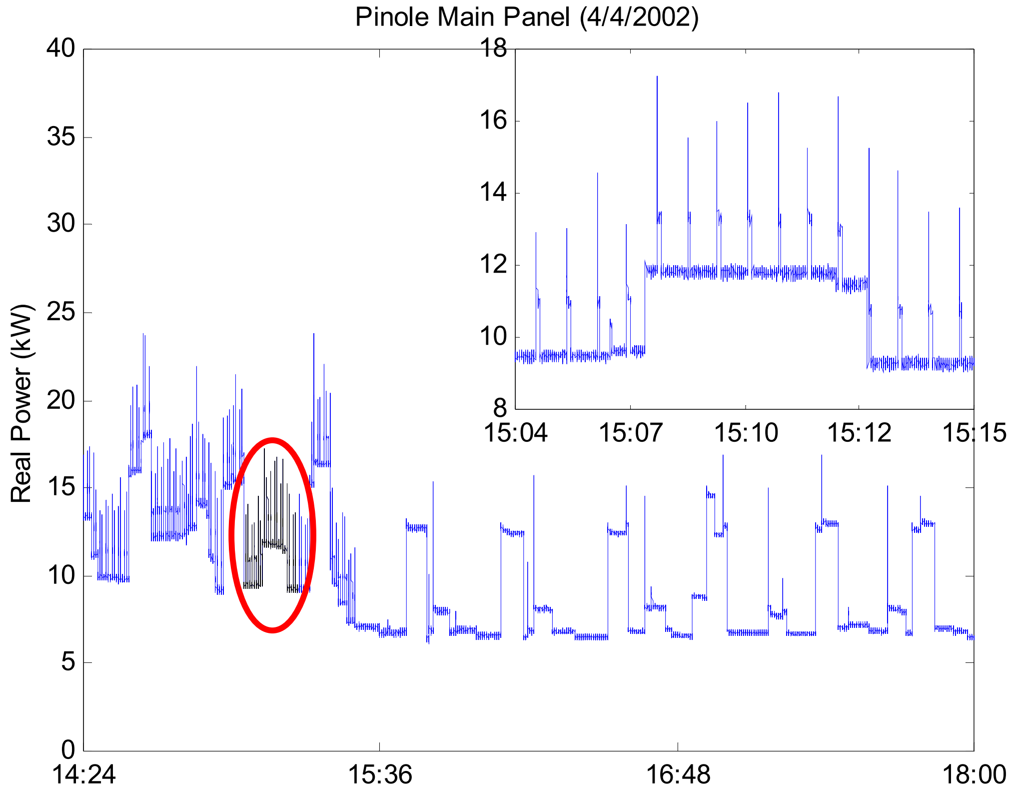

Figure 41 *Pinole Main Panel Consumption Detail on April 4th, 2002.*

The detail figure shows a device turning-on for approximately 6 seconds every 45 seconds. The shape of the device's turn-on transient (Figure 42) is similar to the one exhibited by inductive loads, such as motors.

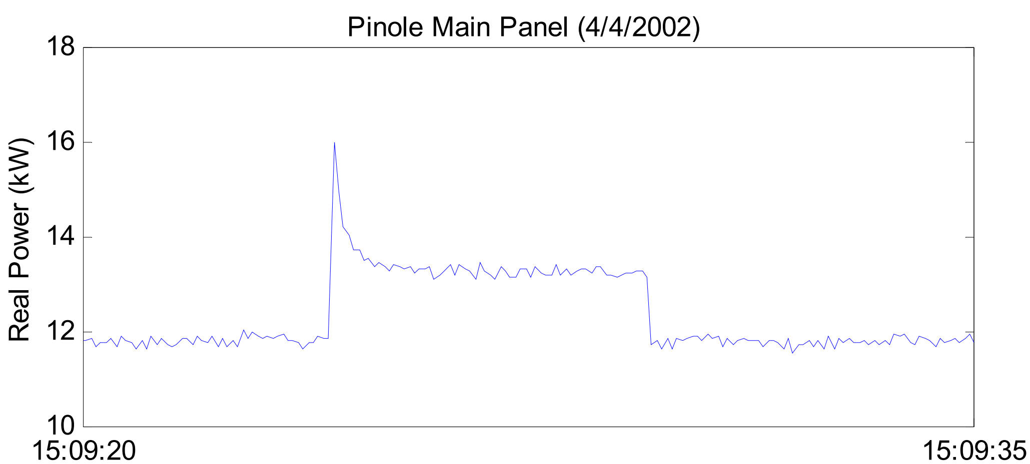

Figure 42 *Turn-on Transient for Oscillatory Device on Pinole Main Panel.*

Secondary Distribution Panel

A NILM machine and a K20 parallel monitoring system were installed on the secondary electrical distribution panel of the Pinole Middle School that services the lights and receptacles of four classrooms. A sample of the real power recorded by the NILM on phase A of the sub-panel is presented in Figure 43 below.

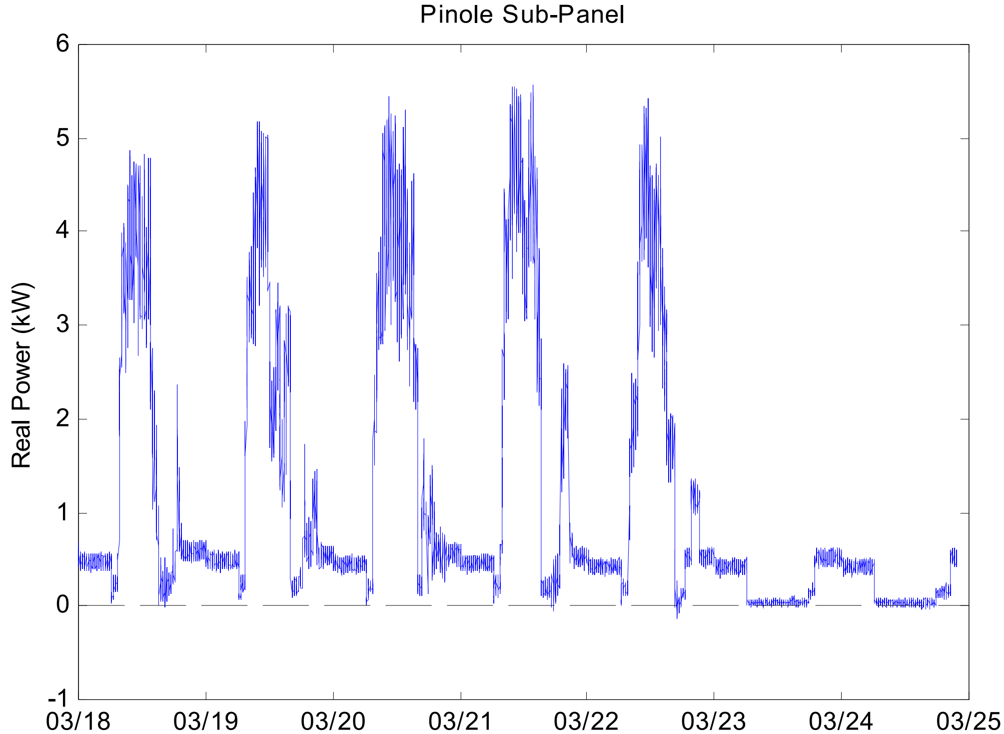

Figure 43 *Pinole Secondary Electrical Panel – Normal Week in March*

The connections at the distribution panel as well as the loads monitored by both the NILM and the K20 systems are shown in Figure 44.

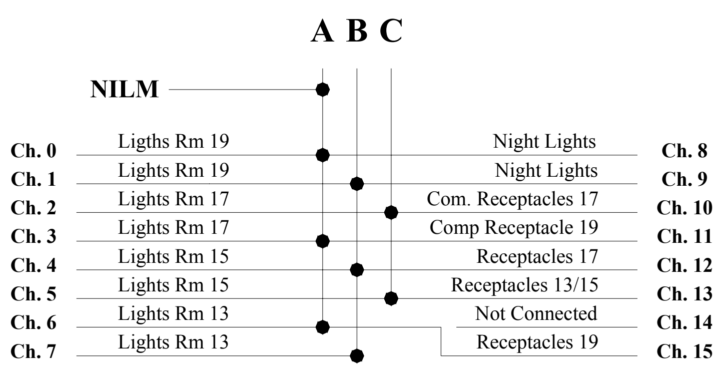

Figure 44 *Pinole NILM and K20 Sub-Panel Connections*

Rooms 17 and 19 are used as a computer laboratory. Room 15 is a normal classroom and room 13 is being used as a librarian office and book storage room. The computer laboratory classrooms are being used to demonstrate the energy consumption savings due to renovations made on those classrooms as part of a plan to reduce the energy consumed by the school. Rooms 13 and 15 are used as control rooms to compare the energy use of the new equipment used in the demonstration classrooms with the equipment prevailing in the school. Table 11 presents a comparison of the equipment used on each demo classroom and the equipment in the control classrooms. All the rooms monitored have the same dimensions (approx. 28'x30') with east facing windows.

***Table 11** Demo and Control Classrooms Equipment Comparison.*

	Demonstration	Control
Fluorescent Tubes (Quant.)	24	49
Type	T8	T12
Power (W)	32	40
Total Power (W)	768	1960
Lumens	2710	1800
Color Rendering Index	78	89
Color Temperature (K)	4100	4200
Incandescent Bulbs (Quant.)	None	3
Power (W)	-	100
Lighting Controls	Motion and Light Sensors	None
Computers	17	3

The following figures present samples of the power data collected by the different K20 channels on the Pinole Sub-Panel. Figure 45 presents two days (Friday and Saturday) of power data from the sub-panel loads other than the classroom lights. Figure 46 shows sample power consumption for the lights in the four classrooms serviced by the sub-panel during the same period of time. Each classroom waveform in the figure is the aggregate power read by two channels of the K20. Two channels per classroom were needed because the lights on each classroom are fed using two phases of the electrical panel. Figure 47 shows the power consumption when the lights are on.

The following observations are made from the mentioned figures:

- The classroom lights are turned on from before noon until around 10:30pm, when the
- The power consumed by the lights in room 19 is greater than that of room 17. The same night-lights are turned on. The night-lights are turned off at about 5:30am.
- As expected, the lights power consumption of the demonstration classrooms (17 and 19) is smaller than that of the control classrooms (13 and 15). However, the difference is not as big as predicted by the values in Table 11. power level was expected given that the same lighting equipment was used in both rooms. The lights consumption of room 17 agrees with the estimations in Table 11.
- The power consumption of the loads connected to the receptacles in rooms 17 and 19 is much greater than the loads in room 13 and 15. This is due to the use of rooms 17 and 19 as computer laboratory.

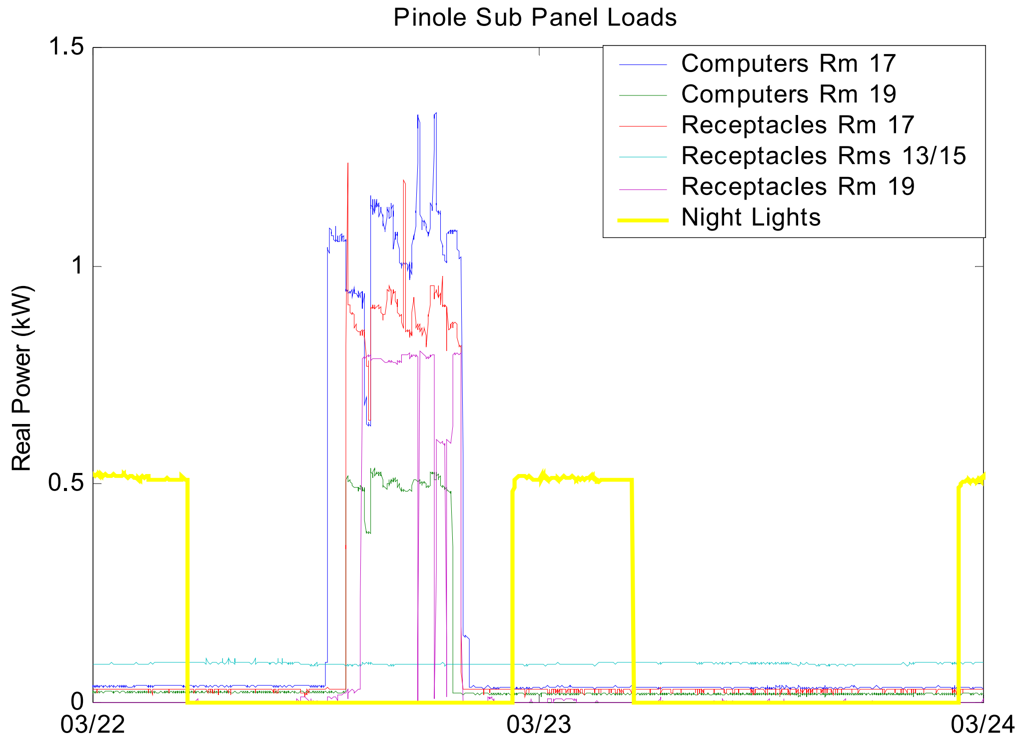

Figure 45 *Sample Consumption of the Sub-Panel Loads (Non-Classroom Lights)*

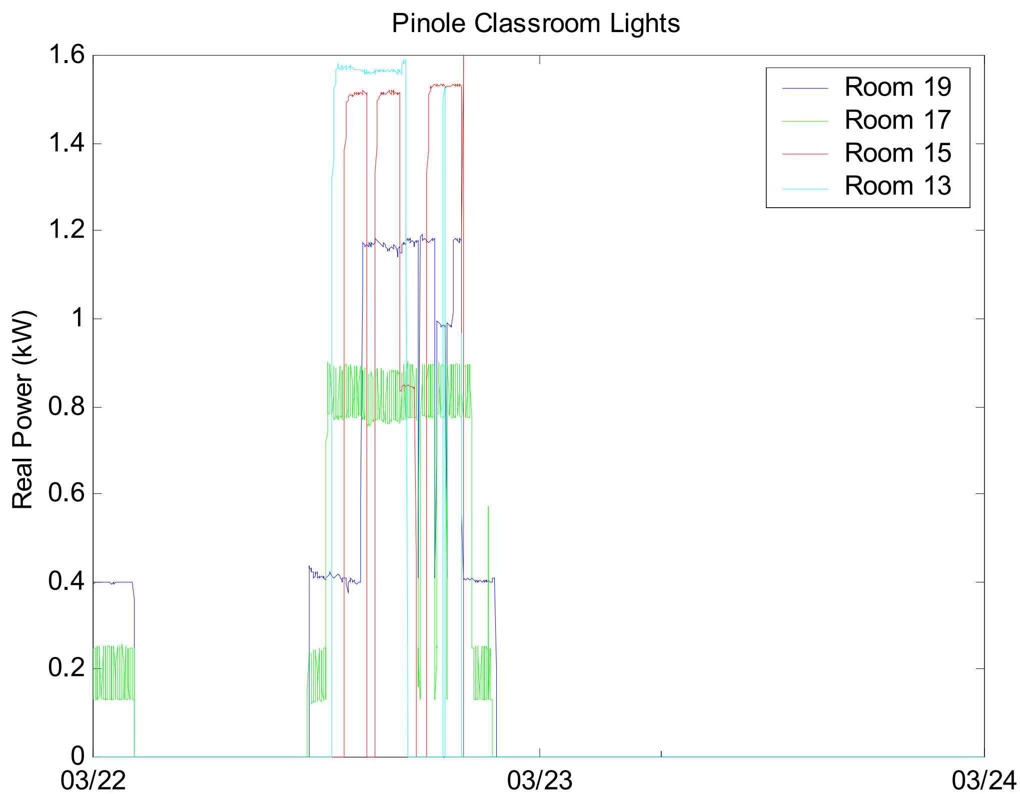

Figure 46 *Sample Consumption for the Classroom Lights (Demo Rooms: 13 & 15).*

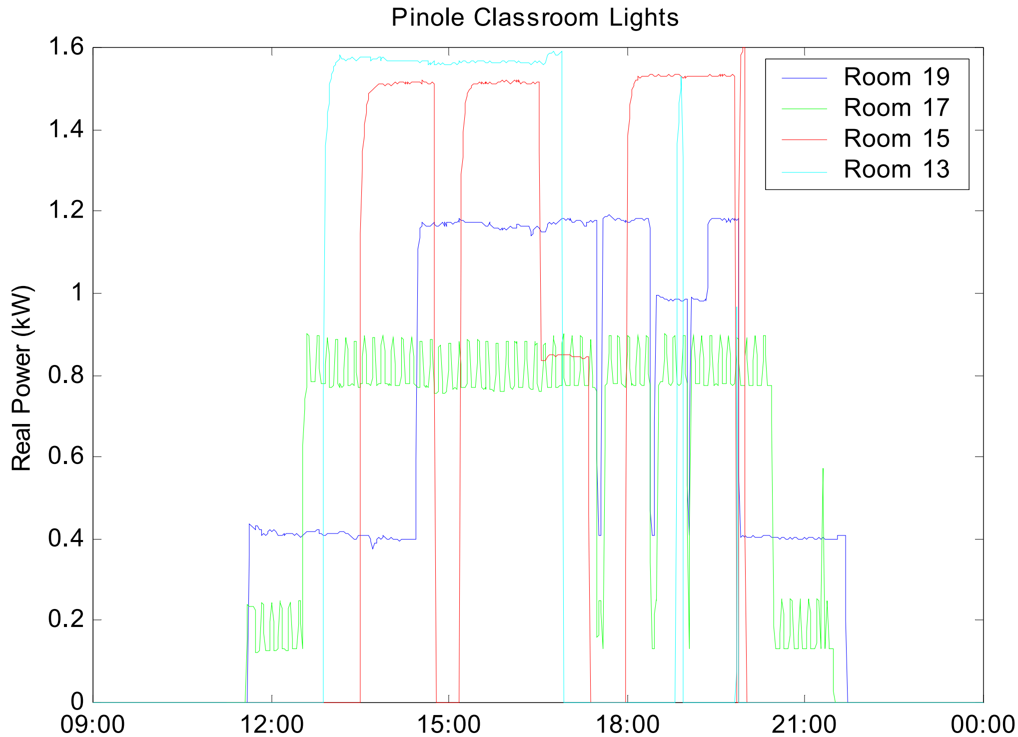

Figure 47 *Sample Power Consumption (Detail) of the Classroom Light.*

The energy consumed by the loads on the monitored sub-panel was estimated from the data collected by the K20 system. Table 12 presents a sample of the energy consumption of the classroom lights during four consecutive weeks, while Table 13 presents the consumption by the loads connected to the classroom receptacles.

Table 12 *Lights Energy (kWh) Consumption*

	3/18/2002	3/25/2002	4/1/2002	4/8/2002	Month Total
Total Lights Room 19	43.35	38.67	5.84	42.75	130.61
Total Lights Room 17	32.44	35.89	7.58	29.34	105.25
Total Lights Room 15	45.30	42.61	0.37	44.74	133.02
Total Lights Room 13	34.53	41.93	1.80	55.29	133.55
Total Night Lights	23.14	23.39	28.04	27.38	101.95

Table 13 *Sub-Panel Loads Energy (kWh) Consumption*

	3/18/2002	3/25/2002	4/1/2002	4/8/2002	Month Total
Computers Room 17	42.91	40.57	6.35	49.02	138.86
Computers Room 19	19.92	19.23	3.41	22.96	65.52
Receptacles Room 17	32.88	27.69	2.32	38.16	101.04
Receptacles Room 19	19.56	15.69	0.04	16.44	51.73
Receptacles Rooms 15/13	15.28	18.60	17.59	17.22	68.69

The lights in room 17 consumed the least amount of energy amongst the classrooms, even though they are on during the same times (Figure 46) as lights in the other three classrooms. Lights in classrooms 13 and 15 consumed approximately the same amount of energy, while classroom 19 lights consumed slightly less energy than rooms 13 and 15.

The non-lighting loads in rooms 17 and 19 consumed more than twice the energy used by the loads in rooms 13 and 15. The computers and related devices in the demonstration classrooms are responsible of the higher non-lighting energy consumption in these rooms.

The high-energy consumption of lights in classroom 19, relative to classroom 17, suggests that the lights in the former room were on during longer periods of time during the month observed. Figure 48 shows the light power consumption patterns during the month studied. It can be seen that the lights in the demonstration classrooms were on during big part of the school holiday period, effectively offsetting the savings that could be attained by the more efficient lighting equipment. Those lights were the lights in room 19.

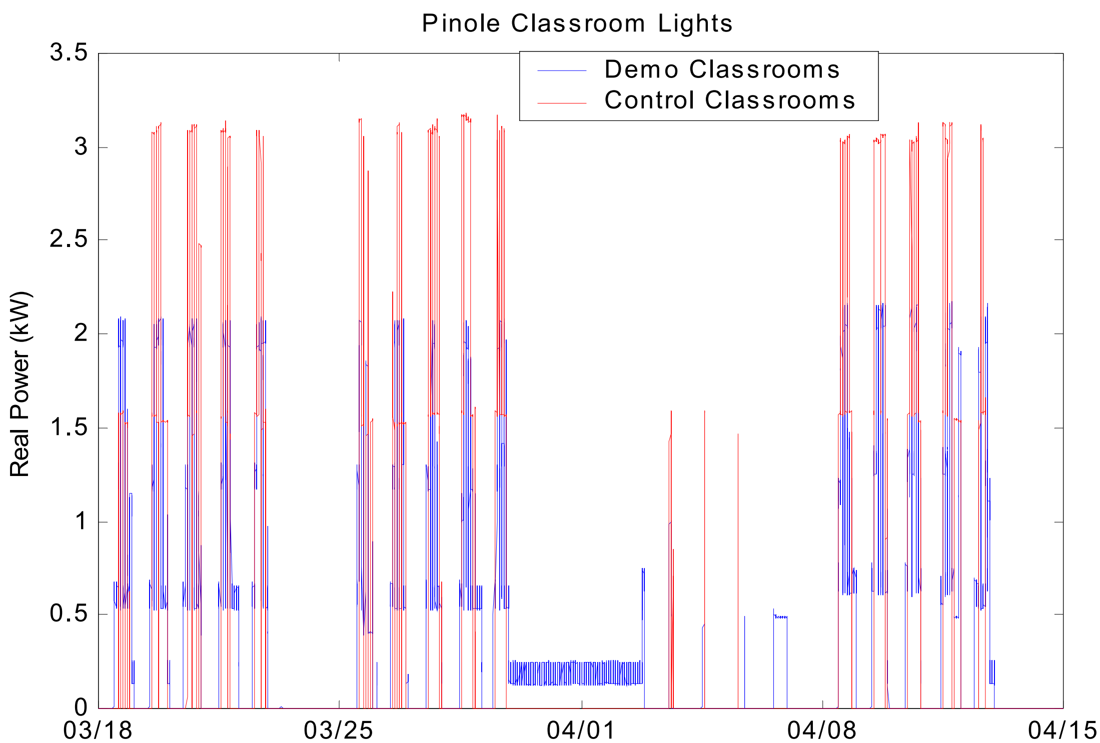

Figure 48 *Lighting Power Consumption during One Month.*

For the four-week period, the energy consumed by the lights in room 17 was **21%** less than energy used by rooms 13 or 15. The energy consumed by room 19 was only **3%** less then that used by rooms 13 or 15. The combined savings of the lights in room 17 and 19 was of **11.5%** relative to energy used in rooms 13 and 15 combined. It is interesting to note that the lights in the demonstration classrooms remained on during longer periods of times than in the control classrooms, therefore reducing the energy saved.

NILM Energy Information Feedback

The Non-Intrusive Load Monitoring system can provide building operators and owners with detailed information on the building's electrical equipment operation in addition to the data provided by conventional power metering systems.

The energy consumed by different devices on a circuit can be tracked using a NILM system, providing detailed time-of-use information. Knowing where and when energy is used helps identify possible energy and cost saving measures. For example, loads that stay on longer than required can be identified, as well as loads operating during peak-times.

The NILM system is also capable of revealing equipment behavior, such as oscillations, that cannot be observed using conventional (low frequency) metering systems. Based on these observations, equipment control strategies can be tuned, for example to reduce cycling and therefore wear and maintenance costs. Abnormal equipment behavior and power consumption, indicative of possible faults, can also be detected and identified using the NILM power data.

Work in the third year of the project will focus on making NILM information available to WCCUSD staff and assessing their use of this information. To this end, NILM output was shared with school officials and others during a series of meetings, described next.

Meetings with Project Collaborators

PG&E Customer Energy Management Group (June 20, 2002)

Meeting Summary

The purpose of the meeting was to review the results of the benchmarking analysis of the WCCUSD schools energy consumption, and to present the current results of the monitoring of Hanna Ranch and Pinole using the NILM and K20.

Meeting Attendees: Andrea Porter, Project Manager; Pamela Murray; Genrick Gofman, Program Manager; Charlie Nadig, Senior Program Manager; Pamela Peak, Strategic Energy Innovations. Contact information for meeting attendees is presented in Appendix H.

Benchmarking Discussion

- PG&E studied WCCUSD school energy consumption (the source of MIT's school energy data), but used fewer indicators than MIT. Members of the Customer Energy Management group liked the presentation of the data in graphical format, and would like to incorporate the benchmarking graphical results into the energy studies they perform for clients. Currently, the energy studies assess the energy consumption of the clients, but do not provide any information as to where that consumption stands relative to other similar use building in the region.
- Suggestions made to improve the benchmarking analysis were the incorporation of weather data, demand data for the schools and monthly energy consumption. MIT should

obtain the monthly data from WCCUSD, although Porter would investigate if PG&E could provide the monthly data to MIT, because WCCUSD already signed a release consent form to PG&E for the original energy study.

School Monitoring Discussion

- The NILM generated positive responses. The ability of the NILM to disaggregate loads using single point metering instead of sub-metering was appealing because PG&E provides clients with Energy Consumption Analysis that involves the installation of power loggers. However, the power loggers are installed by the client and not by PG&E, which has caused problems at the time of collecting the data.
- Andrea Porter asked how much would it cost to install NILMs at other school sites, and how long would it take. She asked this because PG&E is working with the Oakland school district and would like to have more information about the energy consumption than their meters can provide at some of the schools, before they make their recommendation for school improvements.
- Analysis of the energy consumption of the demonstration classrooms at Pinole was welcomed. Pam Murray is working with school designers and officials to promote the use of energy saving measures in schools particularly use of daylight and equipment retrofits. She suggested more detailed and long term (year long) monitoring of the Pinole classrooms. They would like to use the results as a Case Study to present to clients.

WCCUSD HVAC Maintenance Team (June 24, 2002)

Ed van der Linden arranged a meeting with staff of his HVAC maintenance team. Richard Jackson and Patrick Davis explained in broad terms the operation of the HVAC equipment in Hanna Ranch. They reviewed the program (Insight 2.8) they use to program and monitor the Energy Management System (EMS) at Hanna Ranch. The following EMS parameters were obtained from the system demonstrations:

- The school is divided in two zones with the occupied time for the first zone set from 7:30am to 3:30pm, and for the second zone from 7:33am to 3:30pm.
- HVAC temperature set points are at 68°F for heating, 72°F for economizer (damper), and 74°F for cooling.

When asked about the amount of air conditioning used through out the schools in the district, they stated that the information was not documented. They indicated that as a general rule, schools that have portable classroom units have heat pumps for each classroom, and no A/C in the main buildings of older construction. An empirical list was compiled with approximate A/C coverage in the school based on the personal recollection of Jackson and Davis.

WCCUSD Facilities Design Team (June 25, 2002)

Meeting Summary

The purpose of the meeting was to present the benchmarking analysis of WCCUSD schools energy consumption as well as the results from the monitoring of Pinole Middle School and Hanna Ranch Elementary.

Meeting Attendees: Kevin McQuarie, WLC Architects; Venkatesan Cadambi, WLC Architects; Greg Frucci, WLC Architects; Tom Ventura, Seville Group, Inc.; Dave Bautista, Seville Group, Inc.; Tony Catrino, WCCUSD Facilities; Pamela Peak, Strategic Energy Innovations.

Benchmarking Discussion

- The schools with the best energy performance were retrofitted 5-8 years ago under Gary Freschi's energy savings plan. These retrofits include new furnaces, lower ceilings, new lights
- Primary causes of poor energy performance across several schools are lighting and old equipment and buildings. For example Downer Elementary School is lit with 300W incandescent bulbs, and has old boilers (circa 1910) outside of the building.
- Another cause considered as a possible cause for poor performance is the lack of windows, therefore eliminating the possibility of using daylight or natural ventilation.
- Differences in energy consumption might be attributed to different microclimates. According to school officials, there are three microclimates that can be identified in the WCCUSD geographic area (Two climate zones are identified in Contra Costa County by the California Energy Commission). The effect of the weather should be included in the benchmarking analysis.
- Energy use differences were observed among schools of similar size, orientation and location. For example Ohlone and Hercules have similar construction, orientation and climate, but Hercules consumption is significantly higher than Ohlone. Multiple hypotheses were presented to explain the difference in consumption and are going to be investigated further by Tony Catrino et al. Among them might be the possibility that the Day Care Center at Hercules is hooked to the school electricity meter.
- MIT and WCCUSD should work during this year to include weather data and monthly consumption data into the benchmarking analysis. If needed, WCCUSD could provide network drops and space for additional equipment, such as weather stations.
- Include Hercules Middle/High School into energy analysis.
- In order to save energy at the schools the following steps were recommended to be taken:
  - Behavioral changes. Education of building users.
  - Scheduling changes and equipment maintenance. Reduce cost and energy use by keeping equipment in correct working order, and simple modifications to schedules.

- Equipment retrofits. These could vary from the installation of simple control devices like timers and motion sensors, to the replacement of older equipment with newer high efficiency equipment. Changes in building insulation and air infiltration.
- Design changes in buildings, such as daylighting, passive cooling and heating (shading, ventilation, orientation, thermal mass, etc)

<u>School Monitoring Discussion</u>

- Energy consumption results for demonstration classrooms and control classrooms at Pinole Middle School were presented. The lighting retrofits in the demonstration classrooms presented a savings of 20% in energy consumption compared to the lights in the control classrooms
- Hanna Ranch sample of NILM monitoring was presented. An example was shown showcasing the ability of the NILM data to detect abnormal equipment operation. The example used was the rapid on-off cycling of piece of equipment believed to be the A/C. (It was later confirmed that it was the kiln, but the A/C energy use was separated from the kiln via the NILM.)
- Continued monitoring of the demonstration classrooms at Pinole was suggested to obtain conclusive results regarding the energy savings of the multiple retrofits. Next year a new HVAC system in the rooms will be used that was not operational during this year.
- Experiments to be performed at Hanna Ranch were discussed, such as nighttime cooling and the study of A/C energy consumption as a function of various parameters (dead band, set points).
- Nighttime cooling idea raised concerns about comfort, and what the energy implications would be of the room being too cool in the morning, prompting users (or EMS) to use heating before the AC. Guidelines should be developed to address this and other issues.

School Sites Visits (June 21 and 24, 2002)

<u>Pinole Middle School</u>

An inventory of the electrical equipment in both the demonstration classrooms and the control classrooms was performed. Construction and orientation of the classrooms was also studied. The school staff was interviewed in order to learn the class schedules as well as that of the maintenance and non-academic staff. A schematic plan of the school site was obtained, depicting location and type of the various classrooms.

<u>Hanna Ranch Elementary School</u>

The building monitored by the sub-panel NILM was studied. An inventory of the equipment on the electrical panel was performed. The custodian, Rosa Gomez, was interviewed regarding equipment operation, such as the kiln, kiln fan and exhaust fans other than classroom fans, and settings of the nighttime lights.

Conclusions

Benchmarking of the energy consumption of the schools in West Contra Costa Unified School District was performed using multiple indicators of energy and cost efficiency. Absolute and relative indicators were used. Absolute indicators were annual energy and consumption and cost for gas and electricity. The relative indicators were cost and energy consumption per unit of reference (student population and building area) as well as energy intensities and densities per hours of operation of the schools. A ranking index was defined using the benchmarking results obtained using the various indicators in order to present the benchmarking results using a single figure.

The benchmarking results helped identify the schools that would benefit the most from applying energy saving measures. These energy saving measures could range from simple building user education and equipment scheduling changes to equipment retrofits and building modifications.

The electrical power consumption of two schools in the district, Pinole Middle School and Hanna Ranch Elementary School, is being monitored using Non Intrusive Load Monitoring (NILM) systems and commercially available power metering systems (K20). The main electrical distribution panel in each school is monitored as well as a secondary electrical distribution panel.

The secondary panel in the middle school serves four classrooms in the same wing of the building. Two of these classrooms (demonstration classrooms) were retrofitted with energy efficient lights and controls, while the other two classrooms were left untouched in order to use them as a control set to study the effect on the energy consumption due to the classroom retrofits. During a four-week period, the lights in both demonstration classrooms used 11.5% less energy than the lights in the control classrooms. Individually, one of the demonstration classrooms consumed 21% less energy than the control classrooms while the other classroom only used 3% less energy. Lights that remained on in the demonstration classrooms during long periods of unoccupancy significantly reduced the savings achieved by the new energy efficient lights.

Appendix A Schools Characteristics Data

School	Type	Town	Area (sf)	Students	Hrs/Wk	Mth/Yr	Kitch	% A/C
Bayview	ES	San Pablo	49,781	674	*40*	10	Yes	*0*
Castro	ES	El Cerrito	43,125	412	*40*	10	Yes	*10*
Cesar Chavez	ES	Richmond	43,063	649	*40*	10	Yes	*0*
Collins	ES	Pinole	52,051	513	*40*	10	Yes	*20*
Coronado	ES	Richmond	37,467	426	*40*	10	Yes	*5*
Dover	ES	San Pablo	41,050	731	*40*	10	Yes	*20*
Downer	ES	San Pablo	121,086	957	*40*	12	Yes	*5*
El Sobrante	ES	El Sobrante	33,648	351	*40*	10	Yes	*10*
Ellerhorst	ES	Pinole	37,905	463	*40*	10	Yes	*20*
Fairmont	ES	El Cerrito	34,536	429	*40*	10	Yes	*10*
Ford	ES	Richmond	36,272	521	*40*	10	Yes	*0*
Grant	ES	Richmond	50,211	832	*40*	10	Yes	*0*
Hanna Ranch	ES	Hercules	44,195	496	50	10	Yes	100
Harding	ES	El Cerrito	47,690	438	*50*	10	Yes	*10*
Hercules	ES	Hercules	22,858	340	*40*	10	Yes	100
Highland	ES	Richmond	45,007	677	*40*	10	Yes	*20*
Kensington	ES	Kensington	43,473	520	*40*	10	Yes	*10*
King	ES	Richmond	52,956	551	*40*	10	Yes	*0*
Lake	ES	San Pablo	40,908	457	*40*	10	Yes	*0*
Lincoln	ES	Richmond	43,541	565	*40*	10	Yes	*10*
Madera	ES	El Cerrito	33,929	386	*40*	10	Yes	*10*
Mira Vista	ES	Richmond	49,631	390	*40*	10	Yes	*5*
Montalvin	ES	San Pablo	37,947	356	*40*	10	Yes	*0*
Murphy	ES	Richmond	41,135	440	*40*	10	Yes	*0*
Nystrom	ES	Richmond	70,172	693	*40*	10	Yes	*0*
Ohlone	ES	Hercules	45,561	658	60	10	Yes	100
Olinda	ES	El Sobrante	25,129	359	*40*	10	Yes	*50*
Peres	ES	Richmond	62,322	641	*40*	10	Yes	*0*
Riverside	ES	San Pablo	43,901	337	*40*	10	Yes	*20*
Seaview	ES	San Pablo	25,871	331	*40*	10	Yes	*90*
Shannon	ES	Pinole	25,598	289	*40*	10	Yes	*20*
Sheldon	ES	Richmond	41,742	550	*40*	10	Yes	*0*
Stege	ES	Richmond	42,382	471	50	10	Yes	*0*
Stewart	ES	Pinole	39,487	377	*40*	10	Yes	100
Tara Hills	ES	San Pablo	39,943	469	*40*	10	Yes	*80*
Valley View	ES	Richmond	35,998	410	*40*	10	Yes	*20*
Verde	ES	Richmond	38,837	349	*40*	10	Yes	*90*
Washington	ES	Richmond	36,670	418	*40*	10	Yes	*0*
Wilson	ES	Richmond	46,846	551	*40*	10	Yes	*0*
Adams	MS	Richmond	123,803	1097	40	12	Yes	0
Crespi	MS	El Sobrante	125,000	1088	60	10	Yes	10
Helms	MS	San Pablo	158,682	1283	40	10	Yes	10
Pinole	MS	Pinole	78,313	953	75	10	Yes	50
Portola	MS	El Cerrito	126,852	1040	40	10	Yes	20
DeAnza	HS	Richmond	177,762	1438	40	12	Yes	40
El Cerrito	HS	El Cerrito	173,259	1410	40	12	Yes	50
Kennedy	HS	Richmond	189,841	1026	40	10	Yes	100
Pinole Valley	HS	Pinole	160,915	2167	50	10	Yes	40
Richmond	HS	Richmond	226,510	1644	75	10	Yes	100

Appendix B School Energy Consumption Data

School	Elect (kWh)	Gas (Therm)	Total (kBtu)	Contribution Elect	Contribution Gas	Elect Cost	Gas Cost	Total Cost	Contribution Elect	Contribution Gas
Bayview	189559	8216	1468379	44%	56%	$21,197	$5,219	$26,416	80%	20%
Castro	106468	8823	1245565	29%	71%	$11,887	$6,109	$17,996	66%	34%
Cesar Chavez	161242	2335	783667	70%	30%	$16,374	$1,800	$18,174	90%	10%
Collins	146160	16494	2148086	23%	77%	$16,220	$10,613	$26,833	60%	40%
Coronado	111812	8347	1216200	31%	69%	$12,656	$5,295	$17,951	71%	29%
Dover	151807	7800	1297967	40%	60%	$16,896	$5,191	$22,087	76%	24%
Downer	488185	57536	7419245	22%	78%	$51,681	$34,560	$86,241	60%	40%
El Sobrante	83781	5370	822860	35%	65%	$8,930	$3,509	$12,439	72%	28%
Ellerhorst	109939	6592	1034311	36%	64%	$12,818	$4,380	$17,198	75%	25%
Fairmont	80220	4845	758210	36%	64%	$8,137	$3,189	$11,326	72%	28%
Ford	103923	3306	685189	52%	48%	$11,027	$2,398	$13,425	82%	18%
Grant	169211	7840	1361350	42%	58%	$18,465	$5,484	$23,949	77%	23%
Hanna Ranch	185120	2410	872641	72%	28%	$22,064	$1,680	$23,744	93%	7%
Harding	159362	7281	1271846	43%	57%	$17,140	$4,837	$21,977	78%	22%
Hercules	174720	2911	887255	67%	33%	$18,316	$1,716	$20,032	91%	9%
Highland	127462	2693	704207	62%	38%	$13,622	$1,814	$15,436	88%	12%
Kensington	134502	7243	1183221	39%	61%	$13,466	$4,812	$18,278	74%	26%
King	203910	5214	1217150	57%	43%	$23,117	$3,622	$26,739	86%	14%
Lake	186313	3245	960210	66%	34%	$20,483	$2,220	$22,703	90%	10%
Lincoln	120560	7540	1165350	35%	65%	$14,078	$5,353	$19,431	72%	28%
Madera	145655	7937	1290675	39%	61%	$16,354	$4,789	$21,143	77%	23%
Mira Vista	162634	8268	1381709	40%	60%	$18,366	$5,505	$23,871	77%	23%
Montalvin	90480	3326	641320	48%	52%	$8,280	$2,088	$10,368	80%	20%
Murphy	107027	17161	2081260	18%	82%	$11,893	$11,624	$23,517	51%	49%
Nystrom	168381	13171	1891611	30%	70%	$17,898	$8,820	$26,718	67%	33%
Ohlone	241618	300	854420	96%	4%	$26,481	$312	$26,793	99%	1%
Olinda	103082	4376	789318	45%	55%	$11,172	$2,888	$14,060	79%	21%
Peres	162080	14749	2027909	27%	73%	$18,155	$9,828	$27,983	65%	35%
Riverside	113557	7402	1127655	34%	66%	$12,771	$5,024	$17,795	72%	28%
Seaview	138026	2737	744652	63%	37%	$15,311	$1,968	$17,279	89%	11%
Shannon	113050	3031	688831	56%	44%	$11,812	$2,034	$13,846	85%	15%
Sheldon	127777	8634	1299373	34%	66%	$13,261	$5,637	$18,898	70%	30%
Stege	144635	1743	667804	74%	26%	$15,170	$1,480	$16,650	91%	9%
Stewart	133031	5558	1009705	45%	55%	$14,081	$3,736	$17,817	79%	21%
Tara Hills	183120	9446	1569407	40%	60%	$19,363	$5,643	$25,006	77%	23%
Valley View	122175	6094	1026262	41%	59%	$14,087	$3,911	$17,998	78%	22%
Verde	182560	13330	1955890	32%	68%	$19,199	$8,940	$28,139	68%	32%
Washington	113910	13573	1745951	22%	78%	$11,564	$8,616	$20,180	57%	43%
Wilson	110250	10003	1376468	27%	73%	$11,917	$6,678	$18,595	64%	36%
Adams	390377	35958	4927747	27%	73%	$40,016	$24,861	$64,877	62%	38%
Crespi	381600	29700	4272008	30%	70%	$38,332	$19,604	$57,936	66%	34%
Helms	375653	24285	3710224	35%	65%	$37,712	$9,862	$47,574	79%	21%
Pinole	356920	7699	1987729	61%	39%	$37,734	$5,015	$42,749	88%	12%
Portola	343048	29437	4114166	28%	72%	$34,633	$19,275	$53,908	64%	36%

School	Elect (kWh)	Gas (Therm)	Total (kBtu)	Contribution		Elect Cost	Gas Cost	Total Cost	Contribution	
				Elect	Gas				Elect	Gas
DeAnza	889516	30976	6132656	49%	51%	$85,956	$19,621	$105,577	81%	19%
El Cerrito	811517	58347	8603578	32%	68%	$78,485	$38,929	$117,414	67%	33%
Kennedy	1274853	32410	7590855	57%	43%	$124,254	$20,735	$144,989	86%	14%
Pinole Valley	1039381	34908	7037202	50%	50%	$103,819	$21,310	$125,129	83%	17%
Richmond	1548689	21429	7427120	71%	29%	$175,014	$13,892	$188,906	93%	7%

Appendix C School Energy Consumption per Student

School	Energy Density (kBtu/Student)			Cost per Student		
	Electricity	Gas	Total	Electricity	Gas	Total
Bayview	959.16	1218.37	2177.53	$31.43	$7.74	$39.17
Castro	881.03	2139.74	3020.77	$28.83	$14.82	$43.64
Cesar Chavez	848.16	359.96	1208.12	$25.24	$2.77	$28.02
Collins	972.14	3215.16	4187.30	$31.62	$20.69	$52.31
Coronado	896.27	1960.90	2857.16	$29.73	$12.44	$42.17
Dover	708.59	1067.02	1775.60	$23.11	$7.10	$30.21
Downer	1740.57	6012.04	7752.61	$54.00	$36.11	$90.12
El Sobrante	813.66	1528.44	2342.11	$25.42	$9.99	$35.41
Ellerhorst	809.61	1422.71	2232.33	$27.66	$9.45	$37.12
Fairmont	638.53	1130.23	1768.76	$18.98	$7.44	$26.42
Ford	680.17	634.13	1314.30	$21.15	$4.60	$25.75
Grant	693.67	941.92	1635.58	$22.18	$6.59	$28.77
Hanna Ranch	1274.33	486.21	1760.54	$44.51	$3.39	$47.90
Harding	1242.40	1663.57	2905.97	$39.16	$11.05	$50.21
Hercules	1753.41	856.16	2609.57	$53.87	$5.05	$58.92
Highland	642.41	397.78	1040.19	$20.12	$2.68	$22.80
Kensington	882.00	1391.97	2273.97	$25.88	$9.25	$35.13
King	1261.95	945.69	2207.65	$41.93	$6.57	$48.50
Lake	1392.08	710.57	2102.65	$44.85	$4.86	$49.71
Lincoln	728.07	1334.49	2062.57	$24.92	$9.47	$34.39
Madera	1287.53	2056.19	3343.72	$42.37	$12.41	$54.77
Mira Vista	1421.66	2118.16	3539.82	$47.05	$14.10	$61.16
Montalvin	868.02	935.13	1803.15	$23.28	$5.87	$29.15
Murphy	830.59	3903.13	4733.72	$27.05	$26.44	$53.49
Nystrom	829.05	1900.55	2729.60	$25.83	$12.73	$38.55
Ohlone	1252.28	45.57	1297.85	$40.22	$0.47	$40.70
Olinda	979.73	1218.92	2198.66	$31.12	$8.04	$39.16
Peres	863.21	2302.10	3165.31	$28.34	$15.34	$43.68
Riverside	1148.61	2194.24	3342.85	$37.86	$14.89	$52.75
Seaview	1422.83	826.88	2249.70	$46.26	$5.95	$52.20
Shannon	1334.73	1048.77	2383.50	$40.87	$7.04	$47.91
Sheldon	792.70	1569.80	2362.50	$24.11	$10.25	$34.36
Stege	1048.53	370.32	1418.85	$32.23	$3.14	$35.38
Stewart	1204.01	1474.25	2678.26	$37.35	$9.91	$47.26
Tara Hills	1332.24	2014.04	3346.28	$41.29	$12.03	$53.32
Valley View	1016.76	1486.32	2503.08	$34.36	$9.54	$43.90

School	Energy Density (kBtu/Student)			Cost per Student		
	Electricity	Gas	Total	Electricity	Gas	Total
Verde	1783.14	3815.79	5598.92	$54.96	$25.59	$80.55
Washington	930.57	3249.67	4180.25	$27.69	$20.63	$48.32
Wilson	682.31	1814.30	2496.62	$21.61	$12.11	$33.73
Adams MS	1214.22	3277.80	4492.02	$36.48	$22.66	$59.14
Crespi MS	1196.74	2729.74	3926.48	$35.23	$18.02	$53.25
Helms MS	999.03	1892.80	2891.83	$29.39	$7.69	$37.08
Pinole MS	1277.90	807.86	2085.76	$39.59	$5.26	$44.86
Portola MS	1125.49	2830.44	3955.93	$33.30	$18.53	$51.83
DeAnza HS	2110.64	2154.07	4264.71	$59.77	$13.64	$73.42
El Cerrito HS	1963.80	4138.03	6101.83	$55.66	$27.61	$83.27
Kennedy HS	4239.67	3158.82	7398.49	$121.11	$20.21	$141.31
Pinole Valley HS	1636.57	1610.87	3247.44	$47.91	$9.83	$57.74
Richmond HS	3214.26	1303.45	4517.71	$106.46	$8.45	$114.91

Appendix D School Energy Consumption per Unit Area

School	Energy Intensity (kBtu/ft^2)			Cost per ft^2		
	Electricity	Gas	Total	Electricity	Gas	Total
Bayview	12.99	16.50	29.50	$0.43	$0.10	$0.53
Castro	8.42	20.46	28.88	$0.28	$0.14	$0.42
Cesar Chavez	12.78	5.42	18.20	$0.38	$0.04	$0.42
Collins	9.58	31.69	41.27	$0.31	$0.20	$0.52
Coronado	10.18	22.28	32.46	$0.34	$0.14	$0.48
Dover	12.62	19.00	31.62	$0.41	$0.13	$0.54
Downer	13.76	47.52	61.27	$0.43	$0.29	$0.71
El Sobrante	8.50	15.96	24.45	$0.27	$0.10	$0.37
Ellerhorst	9.90	17.39	27.29	$0.34	$0.12	$0.45
Fairmont	7.93	14.03	21.95	$0.24	$0.09	$0.33
Ford	9.78	9.11	18.89	$0.30	$0.07	$0.37
Grant	11.50	15.61	27.11	$0.37	$0.11	$0.48
Hanna Ranch	14.29	5.45	19.75	$0.50	$0.04	$0.54
Harding	11.40	15.27	26.67	$0.36	$0.10	$0.46
Hercules	26.08	12.73	38.82	$0.80	$0.08	$0.88
Highland	9.66	5.98	15.65	$0.30	$0.04	$0.34
Kensington	10.56	16.66	27.22	$0.31	$0.11	$0.42
King	13.14	9.85	22.98	$0.44	$0.07	$0.50
Lake	15.54	7.93	23.47	$0.50	$0.05	$0.55
Lincoln	9.45	17.32	26.76	$0.32	$0.12	$0.45
Madera	14.65	23.39	38.04	$0.48	$0.14	$0.62
Mira Vista	11.18	16.66	27.84	$0.37	$0.11	$0.48
Montalvin	8.14	8.76	16.90	$0.22	$0.06	$0.27
Murphy	8.88	41.72	50.60	$0.29	$0.28	$0.57
Nystrom	8.19	18.77	26.96	$0.26	$0.13	$0.38

School	Energy Intensity (kBtu/ft^2)			Cost per ft^2		
	Electricity	Gas	Total	Electricity	Gas	Total
Ohlone	18.09	0.66	18.75	$0.58	$0.01	$0.59
Olinda	14.00	17.41	31.41	$0.44	$0.11	$0.56
Peres	8.87	23.67	32.54	$0.29	$0.16	$0.45
Riverside	8.83	16.86	25.69	$0.29	$0.11	$0.41
Seaview	18.20	10.58	28.78	$0.59	$0.08	$0.67
Shannon	15.07	11.84	26.91	$0.46	$0.08	$0.54
Sheldon	10.44	20.68	31.13	$0.32	$0.14	$0.45
Stege	11.64	4.11	15.76	$0.36	$0.03	$0.39
Stewart	11.50	14.08	25.57	$0.36	$0.09	$0.45
Tara Hills	15.64	23.65	39.29	$0.48	$0.14	$0.63
Valley View	11.58	16.93	28.51	$0.39	$0.11	$0.50
Verde	16.04	34.32	50.36	$0.49	$0.23	$0.72
Washington	10.60	37.01	47.61	$0.32	$0.23	$0.55
Wilson	8.03	21.35	29.38	$0.25	$0.14	$0.40
Adams MS	10.76	29.04	39.80	$0.32	$0.20	$0.52
Crespi MS	10.42	23.76	34.18	$0.31	$0.16	$0.46
Helms MS	8.08	15.30	23.38	$0.24	$0.06	$0.30
Pinole MS	15.55	9.83	25.38	$0.48	$0.06	$0.55
Portola MS	9.23	23.21	32.43	$0.27	$0.15	$0.42
DeAnza HS	17.07	17.43	34.50	$0.48	$0.11	$0.59
El Cerrito HS	15.98	33.68	49.66	$0.45	$0.22	$0.68
Kennedy HS	22.91	17.07	39.99	$0.65	$0.11	$0.76
Pinole Valley HS	22.04	21.69	43.73	$0.65	$0.13	$0.78
Richmond HS	23.33	9.46	32.79	$0.77	$0.06	$0.83

Appendix E Time Normalized Relative Energy Consumption

School	Energy Intensity per Hour (kBtu/ft^2-hr)			Energy per Student-Hour (kBtu/person-hr)		
	Electricity	Gas	Total	Electricity	Gas	Total
Bayview	1.624	2.063	3.69	119.9	152.3	272.19
Castro	1.053	2.557	3.61	110.1	267.5	377.60
Cesar Chavez	1.597	0.678	2.27	106.0	45.0	151.02
Collins	1.198	3.961	5.16	121.5	401.9	523.41
Coronado	1.273	2.785	4.06	112.0	245.1	357.15
Dover	1.577	2.375	3.95	88.6	133.4	221.95
Downer	1.720	5.939	7.66	217.6	751.5	969.08
El Sobrante	1.062	1.995	3.06	101.7	191.1	292.76
Ellerhorst	1.237	2.174	3.41	101.2	177.8	279.04
Fairmont	0.991	1.754	2.74	79.8	141.3	221.10
Ford	1.222	1.139	2.36	85.0	79.3	164.29
Grant	1.437	1.952	3.39	86.7	117.7	204.45
Hanna Ranch	1.429	0.545	1.97	127.4	48.6	176.05

School	Energy Intensity per Hour (kBtu/ft^2-hr)			Energy per Student-Hour (kBtu/person-hr)		
	Electricity	Gas	Total	Electricity	Gas	Total
Harding	1.425	1.908	3.33	155.3	207.9	363.25
Hercules	3.260	1.592	4.85	219.2	107.0	326.20
Highland	1.208	0.748	1.96	80.3	49.7	130.02
Kensington	1.320	2.083	3.40	110.2	174.0	284.25
King	1.642	1.231	2.87	157.7	118.2	275.96
Lake	1.943	0.992	2.93	174.0	88.8	262.83
Lincoln	1.181	2.165	3.35	91.0	166.8	257.82
Madera	1.831	2.924	4.76	160.9	257.0	417.96
Mira Vista	1.398	2.082	3.48	177.7	264.8	442.48
Montalvin	1.017	1.096	2.11	108.5	116.9	225.39
Murphy	1.110	5.215	6.32	103.8	487.9	591.72
Nystrom	1.023	2.346	3.37	103.6	237.6	341.20
Ohlone	1.508	0.055	1.56	104.4	3.8	108.15
Olinda	1.750	2.177	3.93	122.5	152.4	274.83
Peres	1.109	2.958	4.07	107.9	287.8	395.66
Riverside	1.103	2.108	3.21	143.6	274.3	417.86
Seaview	2.276	1.322	3.60	177.9	103.4	281.21
Shannon	1.884	1.480	3.36	166.8	131.1	297.94
Sheldon	1.306	2.585	3.89	99.1	196.2	295.31
Stege	1.164	0.411	1.58	104.9	37.0	141.88
Stewart	1.437	1.759	3.20	150.5	184.3	334.78
Tara Hills	1.955	2.956	4.91	166.5	251.8	418.29
Valley View	1.448	2.116	3.56	127.1	185.8	312.88
Verde	2.005	4.290	6.30	222.9	477.0	699.87
Washington	1.325	4.627	5.95	116.3	406.2	522.53
Wilson	1.004	2.669	3.67	85.3	226.8	312.08
Adams MS	1.655	4.468	4.31	186.8	504.3	533.09
Crespi MS	0.868	1.980	6.21	99.7	227.5	762.73
Helms MS	1.010	1.913	4.00	124.9	236.6	739.85
Pinole MS	1.003	0.634	4.16	82.4	52.1	309.28
Portola MS	1.153	2.901	2.12	140.7	353.8	291.47
DeAnza HS	2.134	2.178	6.12	263.8	269.3	691.08
El Cerrito HS	1.998	4.209	2.85	245.5	517.3	327.21
Kennedy HS	2.291	1.707	2.92	424.0	315.9	361.48
Pinole Valley HS	2.099	2.066	1.64	155.9	153.4	134.57
Richmond HS	1.505	0.610	4.05	207.4	84.1	494.49

Appendix F School Rankings Based on Analysis

Rank	Energy per Area	Cost per Area	Energy per Student	Cost per Student	Energy per Student-Hr	Energy per ft^2-Hr	Total Energy	Total Cost
1	Highland	Montalvin	Highland	Highland	Ohlone	Ohlone	Montalvin	Montalvin
2	Stege	Helms MS	Cesar Chavez	Ford	Highland	Stege	Stege	Fairmont

Rank	Energy per Area	Cost per Area	Energy per Student	Cost per Student	Energy per Student-Hr	Energy per ft^2-Hr	Total Energy	Total Cost
3	Montalvin	Fairmont	Ohlone	Fairmont	Pinole MS	Pinole MS	Ford	El Sobrante
4	Cesar Chavez	Highland	Ford	Cesar Chavez	Stege	Highland	Shannon	Ford
5	Ohlone	El Sobrante	Stege	Grant	Cesar Chavez	Hanna Ranch	Highland	Shannon
6	Ford	Ford	Grant	Montalvin	Ford	Montalvin	Seaview	Olinda
7	Hanna Ranch	Nystrom	Hanna Ranch	Dover	Hanna Ranch	Richmond HS	Fairmont	Highland
8	Fairmont	Stege	Fairmont	Wilson	Grant	Cesar Chavez	Cesar Chavez	Stege
9	King	Wilson	Dover	Sheldon	Fairmont	Ford	Olinda	Ellerhorst
10	Helms MS	Riverside	Montalvin	Lincoln	Dover	Fairmont	El Sobrante	Seaview
11	Lake	Castro	Lincoln	Kensington	Montalvin	Crespi MS	Ohlone	Riverside
12	El Sobrante	Kensington	Pinole MS	Stege	Lincoln	King	Hanna Ranch	Stewart
13	Pinole MS	Cesar Chavez	Lake	El Sobrante	Lake	Helms MS	Hercules	Coronado
14	Stewart	Portola MS	Bayview	Helms MS	Bayview	Lake	Lake	Castro
15	Riverside	Lincoln	Olinda	Ellerhorst	Olinda	El Sobrante	Stewart	Valley View
16	Harding	Peres	King	Nystrom	King	Stewart	Valley View	Cesar Chavez
17	Lincoln	Stewart	Ellerhorst	Olinda	Ellerhorst	Riverside	Ellerhorst	Kensington
18	Shannon	Sheldon	Seaview	Bayview	Seaview	Harding	Riverside	Wilson
19	Nystrom	Ellerhorst	Kensington	Ohlone	Kensington	Lincoln	Lincoln	Sheldon
20	Grant	Harding	El Sobrante	Coronado	Richmond HS	Shannon	Kensington	Lincoln
21	Kensington	Crespi MS	Sheldon	Castro	El Sobrante	Nystrom	Coronado	Hercules
22	Ellerhorst	Grant	Shannon	Peres	Sheldon	Grant	King	Washington
23	Mira Vista	Coronado	Wilson	Valley View	Shannon	Kensington	Castro	Madera
24	Valley View	Mira Vista	Valley View	Pinole MS	Pinole Valley	Ellerhorst	Harding	Harding
25	Seaview	Valley View	Hercules	Stewart	Wilson	Mira Vista	Madera	Dover
26	Castro	King	Stewart	Hanna Ranch	Valley View	Valley View	Dover	Lake
27	Wilson	Collins	Nystrom	Shannon	Hercules	Seaview	Sheldon	Murphy
28	Bayview	Adams MS	Coronado	Washington	Crespi MS	Castro	Grant	Hanna Ranch
29	Sheldon	Bayview	Helms MS	King	Stewart	Wilson	Wilson	Mira Vista
30	Olinda	Hanna Ranch	Harding	Lake	Nystrom	Bayview	Mira Vista	Grant
31	Dover	Dover	Castro	Harding	Coronado	Sheldon	Bayview	Tara Hills
32	Portola MS	Shannon	Peres	Portola MS	Helms MS	Olinda	Tara Hills	Bayview
33	Coronado	Pinole MS	Pinole Valley	Seaview	Harding	Dover	Washington	Nystrom
34	Peres	Washington	Riverside	Collins	Castro	Kennedy HS	Nystrom	King
35	Richmond HS	Lake	Madera	Riverside	Peres	Portola MS	Verde	Ohlone
36	Crespi MS	Olinda	Tara Hills	Crespi MS	Riverside	Coronado	Pinole MS	Collins
37	DeAnza HS	Murphy	Mira Vista	Tara Hills	Madera	Peres	Peres	Peres
38	Madera	Ohlone	Crespi MS	Murphy	Tara Hills	Pinole Valley	Murphy	Verde
39	Hercules	DeAnza HS	Portola MS	Madera	Mira Vista	DeAnza HS	Collins	Pinole MS
40	Tara Hills	Madera	Washington	Pinole Valley	Portola MS	Madera	Helms MS	Helms MS
41	Adams MS	Tara Hills	Collins	Hercules	Washington	Hercules	Portola MS	Portola MS
42	Kennedy HS	Seaview	DeAnza HS	Adams MS	Collins	Tara Hills	Crespi MS	Crespi MS
43	Collins	El Cerrito HS	Adams MS	Mira Vista	DeAnza HS	Collins	Adams MS	Adams MS
44	Pinole Valley	Downer	Richmond HS	DeAnza HS	Murphy	Washington	DeAnza HS	Downer
45	Washington	Verde	Murphy	Verde	Adams MS	Adams MS	Pinole Valley	DeAnza HS
46	El Cerrito HS	Kennedy HS	Verde	El Cerrito HS	Verde	El Cerrito HS	Downer	El Cerrito HS
47	Verde	Pinole Valley	El Cerrito HS	Downer	Kennedy HS	Verde	Richmond HS	Pinole Valley
48	Murphy	Richmond HS	Kennedy HS	Richmond HS	El Cerrito HS	Murphy	Kennedy HS	Kennedy HS
49	Downer	Hercules	Downer	Kennedy HS	Downer	Downer	El Cerrito HS	Richmond HS

Appendix G WCCUSD Ranking Results

Ranking Index		Star Score	
Highland	3	Ford	99
Ford	4	Highland	99
Montalvin	4	Cesar Chavez	98
Stege	5	Fairmont	98
Fairmont	6	Montalvin	98
Cesar Chavez	7	El Sobrante	97
El Sobrante	11	Grant	97
Hanna Ranch	14	Hanna Ranch	97
Lincoln	14	Stege	97
Ohlone	14	Dover	96
Ellerhorst	16	Lincoln	96
Grant	16	Ellerhorst	95
Kensington	17	Kensington	95
Olinda	19	Olinda	95
Shannon	19	Wilson	95
Dover	20	Castro	94
King	20	Ohlone	94
Lake	20	Sheldon	94
Stewart	20	Valley View	94
Wilson	20	Bayview	93
Sheldon	21	Coronado	93
Pinole MS	21	Nystrom	93
Castro	22	Shannon	93
Riverside	22	King	92
Seaview	22	Lake	92
Valley View	22	Riverside	92
Nystrom	23	Seaview	92
Helms MS	23	Stewart	92
Bayview	24	Harding	90
Coronado	25	Peres	90
Harding	25	Pinole MS	90
Mira Vista	31	Helms MS	88
Peres	31	Mira Vista	87
Hercules	32	Madera	86
Crespi MS	32	Hercules	84
Madera	34	Tara Hills	84
Portola MS	35	Washington	84
Washington	36	Collins	83
Tara Hills	37	Murphy	82
Richmond HS	37	Crespi MS	81
Collins	38	Portola MS	77
Murphy	40	Adams MS	69
Pinole Valley HS	40	Richmond HS	69
Adams MS	41	Verde	66
DeAnza HS	42	Downer	59
Verde	43	DeAnza HS	59
Kennedy HS	45	Pinole Valley HS	59
Downer	46	Kennedy HS	52
El Cerrito HS	46	El Cerrito HS	51

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